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THE PLANTERSVILLE METEORITE, GRIMES COUNTY, TEXAS

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INTRODUCTION

The Plantersville meteorite fell September 4, 1930, at about 4:00 P.M. at a point near the southeast corner of the A. W. Greenwood 1900 acre tract in the Joel Greenwood Survey, about 3½ miles southwest of Plantersville, Grimes County, Texas, longitude 95° 52′ W., latitude 30° 20′ N. This locality is forested and only the fact that six men (John Caraway, Ernest Caraway, Wilbur Caraway, Henry Bodkins, Ben Kirk, and Jerry Parrish) were cutting timber within a few hundred yards of the point of fall permitted the finding and recovery of the meteorite. Mr. John Caraway secured the specimen and retained possession of it until June 1935. The specimen now is in the collections of the U. S. National Museum.

The details of the phenomena of fall of this meteorite have been secured from two of the observers, John Caraway and Ernest Caraway. Their first impression of an unusual occurrence was that of hearing a distant explosive rumbling at a high angle in the sky. They estimated that this lasted about two minutes. The rumbling noise was succeeded by a noise like an airplane which lasted several minutes and which seemed to come from the southwest and pass the observers before stopping. As this noise stopped some of the men heard a noise like that of a "chunk falling from a tree." At this time the observers thought an airplane had fallen nearby and they moved in the direction from which they heard the last sound. As they moved through the woods in a line with several yards interval, Mr. John Caraway observed two freshly broken tree limbs, 2½ inches in diameter, in an area where no timber cutting had been carried on. As the men searched in this area the meteorite was found protruding slightly above the surface of the ground, which here was composed of compact hard, dry, clay soil. The observers estimated that not more than five minutes elapsed from the start of the search until the discovery, and that the meteorite was picked up within a few minutes of the time of discovery. It was reported to be "milk-warm," and that the hard soil at the place of impact was pulverized for several inches around the pit made by the impact.

The explosive rumbling which was the first evidence of the fall, apparently, was heard over a considerable area since others than the six men previously mentioned remember this phenomenon. However, as far as can be learned, notices of this or of the fall and recovery of the meteorite did not appear in newspapers of the region.

External Features of the Meteorite

The meteorite is a very perfect specimen which as received has been marred by the removal of two small flakes of the crust. The specimen as received weighed 2084.9 grams. A small portion has been cut from one corner to provide material for study and to permit polishing of a fresh surface. Before cutting, the dimensions were $5\frac{3}{4}'' \times 4'' \times 3\frac{3}{4}''$, measured in the three principal directions. The specific gravity determined from a bulk sample, evacuated of air, is 3.71.

The specimen is prominently faceted with ten bounding faces some of which are concave, others convex. In addition, it is subconoid in shape due to rounding of the apex of a prominent octahedral solid angle. It is evident from the shape and character of surface markings that the meteorite was oriented in flight. The four faces bounding the cones were the exposed forward portion (*brustseite*), the remaining faces occupied a lee position less exposed to the air stream. On the forward faces fine thread lines are well developed radiating from the apex of the cone and disappearing or becoming faint at the intersections with the rear faces (Fig. 1).

The surface is covered with a dense black glassy crust. On the rear face this is much rougher than on the exposed faces. There are a few coarse thread lines, but the general appearance is pitted (Fig. 2). The crust is generally less than 0.5 mm. in thickness with the greatest thickness over the rear pitted face.

Megascopically the meteorite, on a fresh surface, is light gray in color but soon assumes a brownish tint due to oxidation of grains of metallic iron. This distribution of the metallic constituents is shown in Fig. 3(1). The surface shown in this figure is traversed by fine cracks filled with metal so that there is an appreciable amount of brecciation. This polished surface also shows the specimen to contain many chondrules, many of which are angular or fragmented, set in a crystalline base of grains of a brownish gray mineral. The chondrules are light gray (pyroxene) and colorless (chrysolite) in appearance. The bulk material of the meteorite is friable but is sufficiently coherent to take a polish and permit the cutting of sections without fracturing.

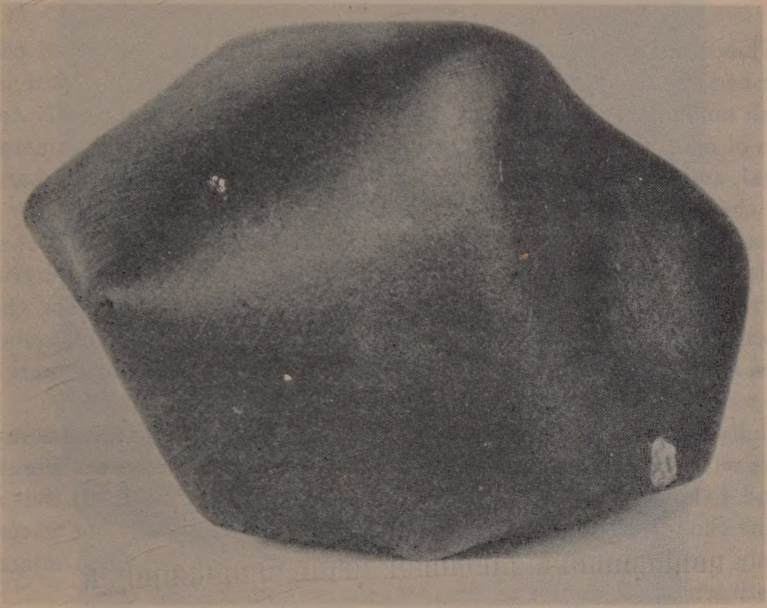

FIG. 1.

Front view of the meteorite showing the subconoid development and fine thread lines radiating from the cone apex.

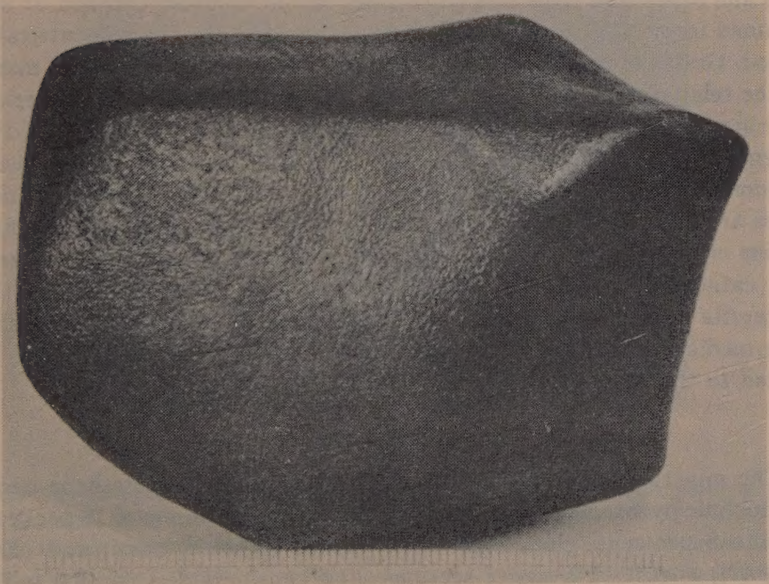

FIG. 2.

Rear view of the meteorite showing the thicker and coarser crust.

STRUCTURE

Thin sections confirm the general structural features observed on a polished surface. Nearly all of the specimen is crystalline, but there is a small amount of glass, largely interstitial. The structure typically consists of many chondrules in a ground mass of grains of silicate minerals, metal, and troilite, with approximately the same range in size as that of the chondrules. Relatively few of the chondrules are perfect, most of them exhibit irregularities in shape or are actually fragments of chondrules. A considerable number of the chondrules are of the porphyritic or fragmental type and are of comparatively large size so that they appear to blend into the general field of silicate grains. Low magnifications reveal such structures and show that a surprisingly large part of the complete specimen is composed of chondrule material.

Individual chondrules vary considerably in composition and structure, more so perhaps than is usually the case in a single meteorite. Figures 3 and 4 show some of the more striking types. It is to be noted that all of the chondrules are crystalline though interstitial glass is not uncommonly present in them. Pyroxene and chrysolite are the main mineral constituents, but do not appear in the same chondrules.

The chrysolite chondrules include the common barred monosomatic type, twinned barred forms with a large amount of glass, porphyritic types with a few subhedral crystals, and fragmental types consisting of angular and rounded fragments of the mineral in a glass matrix (Figures 5(2) and 6(5)). The pyroxene chondrules include radiate twinned or untwinned forms and monosomatic types, some of which are concentrically zoned. Grains of metal are common in all types of chondrules and many of the relatively perfect chondrules are partly rimmed by this material. The size range of all chondrules is 0.1 mm. to 2 mm., but some of the fragments of chondrules must have been from much larger structures.

Some of the fragments of large chondrules and certain areas of grained mass are minutely granular. These consist of an aggregate of very fine grains of pyroxene, chrysolite and metal. The texture resembles closely the cataclastic texture of metamorphic rocks. In classification the meteorite is intermediate between white chondrite, veined (Cwa), and intermediate chondrite (Cia). The prefix hypersthene might well be added to the appropriate name.

MINERALOGY

The mineral constituents of the meteorite include hypersthene and a monoclinic pyroxene 40 per cent, chrysolite 30 per cent, metal 19 per cent, troilite 5 per cent, glass 5 per cent, brown spinel, a trace; and chromite (?), a trace. A series of sections show considerable variation in the

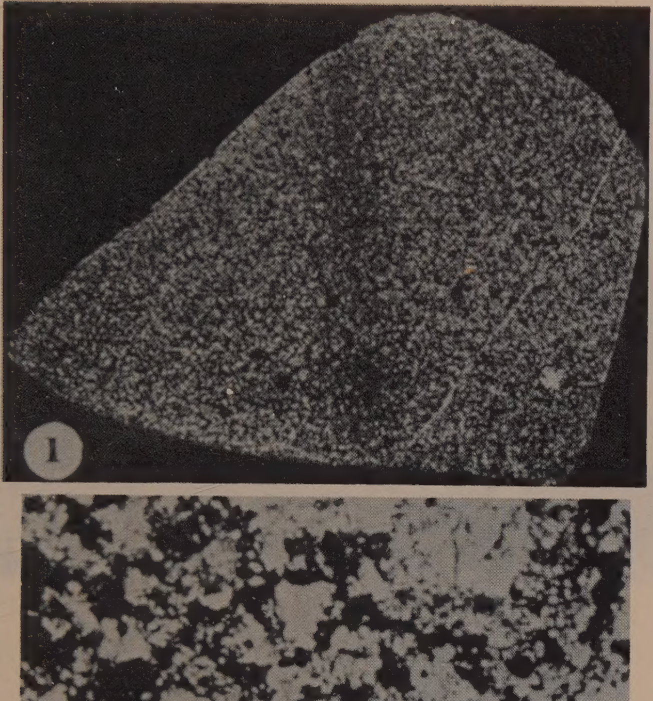

FIG. 3.

(1) View of a polished surface oriented to reflect light from the metallic portions. The vein and small white areas are metal and troilite. Slightly reduced.

(2) Photomicrograph showing texture. The radiate pyroxene chondrule is rimmed with metal. The angular chondrule in lower right is typical of many of the chondrules. Polarized light. ×26.

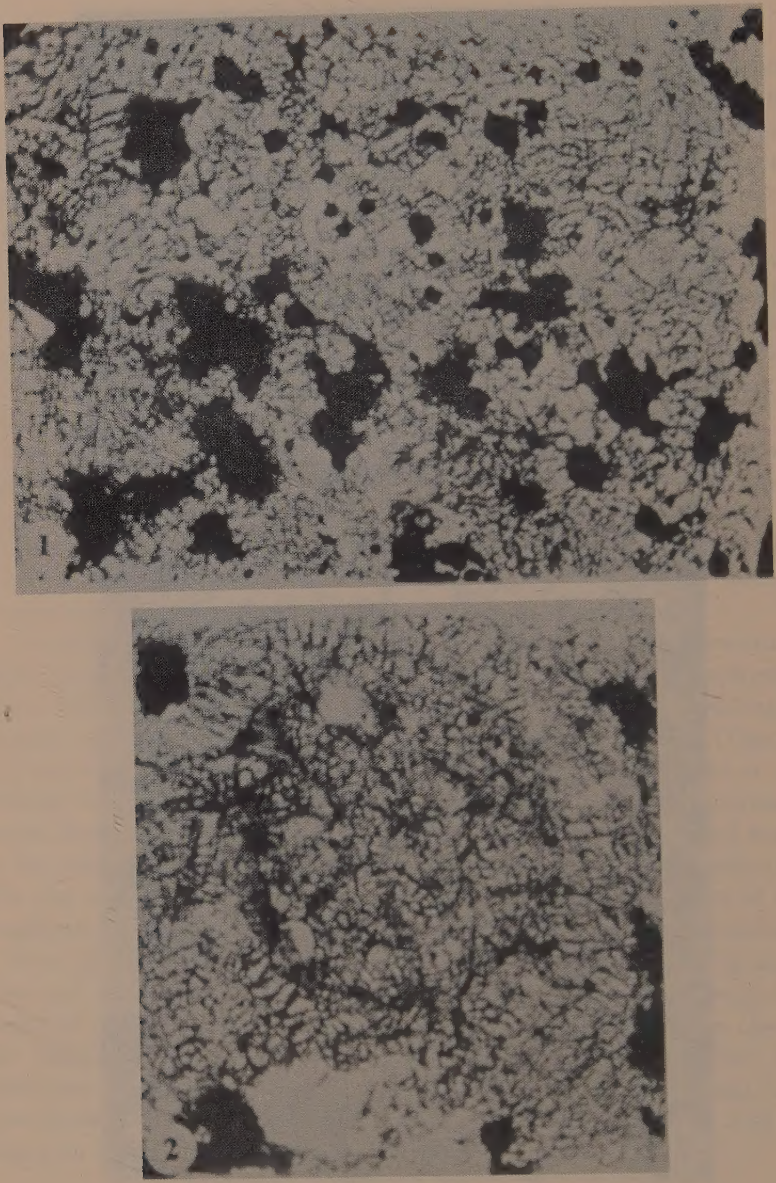

Fig. 4.

(1) Photomicrograph ×100 showing colorless glass, pyroxene with prominent cleavages and black metal.

(2) Monosomatic pyroxene chondrule with outer concentric zone in optical continuity with inner part. ×100.

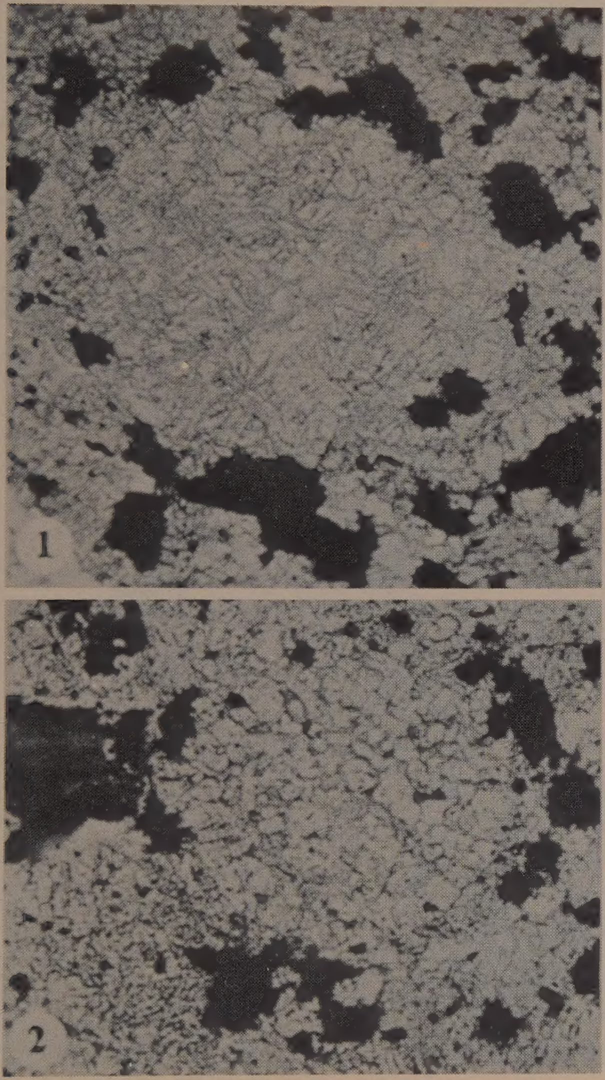

FIG. 5.

(1) Porphyritic chrysolite chondrule. A few of the crystals are subhedral. Glass forms the matrix. ×100.

(2) Fragmented chrysolite chondrule with glass matrix. Black area at left is dark glass surrounded by colorless glass. ×100.

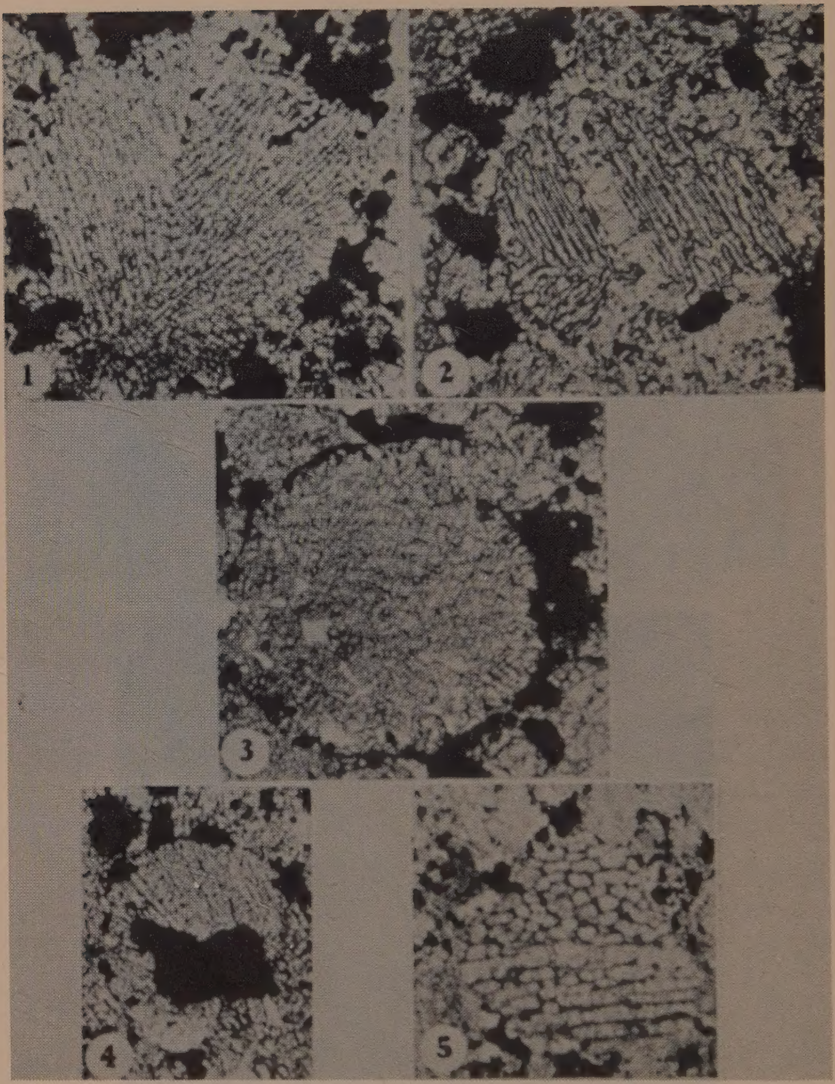

Fig. 6.

(1) Twinned radiate pyroxene chondrule. ×100.

(2) Barred chrysolite chondrule with glass occupying areas of low relief. ×100.

(3) Monosomatic pyroxene chondrule with metal rim. Some of the small white areas are glass. ×100.

(4) Radiate pyroxene chondrule with metal inclusion. ×100.

(5) Barred monosomatic chrysolite chondrule. ×100.

amounts of the minerals, and the mode stated is therefore approximate.

Pyroxenes. Pyroxenes either in chondrules or separate grains are the most abundant minerals of the meteorite. Two varieties, hypersthene and a monoclinic pyroxene, are present, but the latter is present in very small amounts. The two minerals could not be separated in heavy liquids because there is so much glass included in both in variable amounts that a continuous rather than fractional separation results. In thin sections, only rarely are grains observed exhibiting inclined extinction, but in the heavy concentrate consisting of both minerals, one out of ten grains oriented to show the emergence of an optic axis gave a positive optical character. Figures 4 and 6 (3, 4) show occurrences of the pyroxene minerals. The hypersthene is grayish in thin section, very slightly pleochroic and occasionally shows multiple twinning. Grains with observable prismatic cleavage show straight extinction, $\gamma=1.678$, $\gamma-\alpha=.013$, large optic axial angle, and negative optical character.

The monoclinic pyroxene resembles the hypersthene. In the few grains identified a maximum extinction angle of 28° was observed. The mineral is optically positive and has a moderate optic axial angle. The indices of refraction have not been measured except that they are within the limits of those given for hypersthene. These facts, together with the rather large amount of lime shown in the chemical analysis of the insoluble part of the specimen, lead to a tentative identification of the mineral as pigeonitic pyroxene.

Chrysolite. The chrysolite, like the pyroxene minerals, occurs both in the chondrules and in separate grains. A few subhedral crystals are present in both occurrences. Figure 6 (2, 5) shows the mineral in chondrules. The chrysolite is optically negative, with a large optic axial angle, $\gamma=1.707$, and $\gamma-\alpha=.038$. The iron rich character indicated by these optical data is confirmed by the chemical analysis of the soluble part of the meteorite.

Metal. The metal is disseminated throughout the specimen in grains, veinlets, and as rims surrounding chondrules. The grains are irregular in outline and reach 0.7 mm. in greatest dimension. Certain grains show troilite continuous with the metal. The veinlets apparently are contemporaneous with the grains of metal since they, in many cases, lead from the grains and in no case appear to occupy fractures in grains of the metal. The veinlets characteristically consist of numerous irregular grains of metal connected by thin threads of the same material.

Troilite. Troilite is much less abundant than metal and occurs generally in smaller grains. It is present to a limited extent in the veinlets and generally shows a tendency toward association with the metal.

Glass. An isotropic substance, presumably glass rather than a crystalline material occurs as interstitial grains in the general mass of the specimen, in several types of chondrules, and in fine grained aggregates with silicate minerals. The glass has an index refraction of 1.510 and hence probably is not *maskelynite*, the glass of many meteorites.

The interstitial glass is colorless and is present in grains of very irregular shape. These appear to occupy space left between mineral grains and chondrules. At times such grains contain inclusions of the silicate minerals. Interstitial glass is shown in Fig. 4 (1).

Many of the chondrules contain glass. Figure 6 (2) shows a chrysolite chondrule with a large amount of glass which appears to be one connected body in which the bars of the chrysolite are supported. Glass is present in the chondrules of Fig. 4 (2), Fig. 5 (2), and Fig. 6 (2), but in these cases it is not so abundant or easy to distinguish.

Sections of the meteorite show many irregular fragmental aggregates of minerals and also irregularly shaped chondrules composed of fragmental mineral grains. These invariably contain glass and the relation between the constituents suggests a cataclastic texture.

Chromite (*?*). Associated with the troilite and metal of the specimen is a very small amount of a black opaque mineral. Since the chemical analysis shows a small amount of chromium oxide, this mineral is tentatively identified as chromite.

Brown Spinel. A brown isotropic mineral with high index of refraction occurs as minute inclusions in the silicate minerals. These are globular to roughly octahedral in shape, and the mineral is tentatively identified as spinel.

CHEMISTRY

A chemical analysis of the specimen was made by F. A. Gonyer and is given below:

Metallic portion:	19.03%
Soluble silicates and sulphides:	39.04
Insoluble silicates:	41.93

	Insoluble Silicates	Soluble Silicates Sulphides	Metallic Portion	Composite
SiO_2	55.55	32.23		35.87
Al_2O_3	4.37	0.86		2.18
FeO	11.17	19.01		12.10
MgO	22.01	36.74		23.57
CaO	3.61	1.19		1.97
Na_2O	2.52	—		1.05
K_2O	0.31	—		0.12
P_2O_5	None	0.15		0.05
Cr_2O_3	0.08	—		0.03

MnO	032	0.13		0.18
TiO_2	None	None		None
NiO	None	0.04		0.01
CoO	None	None		None
S	—	*3.73		1.45
Fe	—	*6.48	89.28	16.99
Ni	—	—	10.12	1.92
Co	—	—	0.36	0.06
Cu	—	—	0.04	Trace
P	—	—	0.02	Trace
Sum	99.94	100.56	99.82	97.55

*Iron and sulphur in troilite

The insoluble silicate portion corresponds to the pyroxene of the specimen except that most of the alumina, lime, soda and potash, possibly, are present in the glass. If all of the soda and potash are allotted to alumina, and excess alumina to lime, the normative plagioclase *ab 89*, *an 11* results. The low index of refraction of the glass (1.510) indicates that it corresponds to an alkali feldspar. The iron to magnesium ratio indicates a pyroxene of the hypersthene type. The soluble silicate portion is essentially the chrysolite of the specimen. The iron to magnesium ratio suggests a chrysolite corresponding fairly well with the observed mineral.

A norm calculated for the analysis is as follows:

Orthoclase	0.56
Albite	8.91
Anorthite	1.11
Diopside	6.70
Olivine	47.93
Hypersthene	12.30
Fe_nNi_m	18.99
Troilite	3.98

A spectographic analysis of the three portions of the meteorite, made by Dr. H. C. Wilhelm, revealed the presence of germanium and titanium in addition to the constituents reported in the chemical analysis. The complete spectographic analysis is given.

	Na	Mg	Ca	Al	Ti	Si	Ge	Co	Cr	Mn	Ni	Fe	K
Metallic portion	2	2	4	4	5	2	4	3	2	4	2	1	
Soluble silicate	2	2	4	4	0	2			3	5	3	3	
Insoluble silicate	2	2	4	4	5	2			2	5	5	3	4

Intensities: 1 strong, 2 present, 3 weak, 4 trace, 5 very faint trace.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to a number of people who have aided in the securing and description of the Plantersville Meteorite. Dr. Lamar Jones of Bryan, Texas, first learned of the specimen and was instrumental in obtaining it from Mr. Caraway. Dr. W. F. Foshag of the United States National Museum, arranged for the cutting of the specimen and preparation of thin sections. Dr. H. A. Wilhelm very kindly made the spectographic analysis quoted, and Dr. Louis Lykken determined the specific gravity. The chemical analysis was made possible by a grant from the Industrial Science Research Funds, Iowa State College.

PETROLOGIC RESULTS OF A STUDY OF THE MINERALS FROM THE TERTIARY VOLCANIC ROCKS OF THE SAN JUAN REGION, COLORADO[24]

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(*Continued from p. 701, (November), 1936*)

5. THE AMPHIBOLES

By Esper S. Larsen and John Irving

Occurrence

Amphiboles are one of the chief mafic minerals in the San Juan area but they are somewhat subordinate to diopside and biotite, both in absolute amount and in the number of lavas which carry them. Amphiboles are absent from the basaltic rocks and from the andesites near the basalts, namely from all rocks with less than 53 per cent of SiO_2. Biotite is very rare in rocks with less than 57 per cent of SiO_2. Both biotite and hornblende are less common and less abundant in the andesites than in the latite-andesites. They are present in most of the quartz latites. In the Alboroto quartz latites, amphiboles are present together with phenocrysts of biotite, plagioclase, orthoclase, quartz and titanite, and rarely diopside. In the Piedra quartz latites they are present together with the same assemblage of minerals as in the Alboroto with the addition of diopside. In the Treasure Mountain quartz latites, which contain phenocrysts of plagioclase, biotite, and diopside, amphiboles are entirely absent.

In the rhyolites, biotite is commonly the only mafic mineral present in appreciable amounts, but many of them show either hornblende or pyroxene, or both, in such small amounts that either several thin sections must be examined, or a heavy liquid separation made to find them; their proportion is less than 0.1 per cent.

In the granular intrusive rocks hornblende is probably somewhat less common than in the lavas. It is rare as a hydrothermal mineral. In many of the gas cavities of the andesitic lavas tiny needles of hornblende are present with tridymite or cristobalite and other minerals.

Resorption

In most of the lavas the amphiboles show more or less resorption and this resorption appears to be more extensive in the andesites than in the rhyolites. It is nearly or quite lacking in the rocks with glassy groundmass, indicating that much of the resorption took place after the lavas were erupted. This is also indicated by the fact that the dust of iron oxide left from the hornblende is not strewn about. All stages of resorption were found, from incipient etching and staining by iron oxide on the borders of the crystals, to complete removal of the amphibole. The stages in the resorption are excellently shown in the stocks and associated dikes of the small intrusive of Fisher diorite of Red Mountain near the southeastern corner of the San Cristobal quadrangle, a few miles south of Piedra Peak. Here the small apophyses and the border of the mass carry abundant hornblende phenocrysts (showing little or no resorption) in a fine groundmass that has a little diopside and hypersthene. In the larger bodies, and farther from the contact, the resorption of the hornblende becomes progressively greater. A dust of black iron ore, some reddish brown grains of hematite (?), some diopside, feldspar and some undetermined material are deposited where the hornblende has been removed. The groundmass becomes coarser and contains tiny grains of pyroxene.

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[24] Published with the permission of the Director of the U. S. Geological Survey, Washington, D.C.

Farther in from the contacts the resorption proceeds through a stage where only remnants of hornblende remain to one in which only the dust of iron oxide marks the former presence of hornblende. At this stage the amount of pyroxene is greater, the grains are larger and they are not spatially associated with the resorbed hornblende. Finally, in the granular rock all signs of the hornblende have been removed and the pyroxene has all the appearances of a normal early crystallized mineral.

In many of the lavas, hornblende shows similar resorption but it has not been followed step by step. A group of andesites of Fisher age in the southeastern part of the San Cristobal quadrangle, on both sides of Red Mountain Creek, show the resorption very well. Some specimens have phenocrysts of quartz and hornblende with little resorption, others show all stages in the resorption of both minerals, even to their complete disappearance. The resorbed quartz grains show the coronas of tiny diopside grains characteristic of quartz phenocrysts in basalts. As the hornblende is resorbed, diopside appears, first in and near the resorbed hornblende, then scattered through the groundmass, and finally as phenocrysts. The rocks in which the quartz and hornblende have been resorbed have tridymite in the gas cavities.

The resorption of hornblende yields chiefly magnetite, hematite, feldspar, and a pyroxene much poorer in total iron than the hornblende from which it was derived, as shown by the optical properties of the pyroxene. In a few specimens irregular shreds of pale biotite are present; in one, some matted, pale green hornblende. In some of the specimens tiny rods or irregular growths of diopside grow out from the resorbed hornblende. Much of the pyroxene in and about the resorbed hornblendes is brown from partial oxidation of its iron.

Figures 9 and 10 are photomicrographs to show the stages in the resorption of the hornblende.

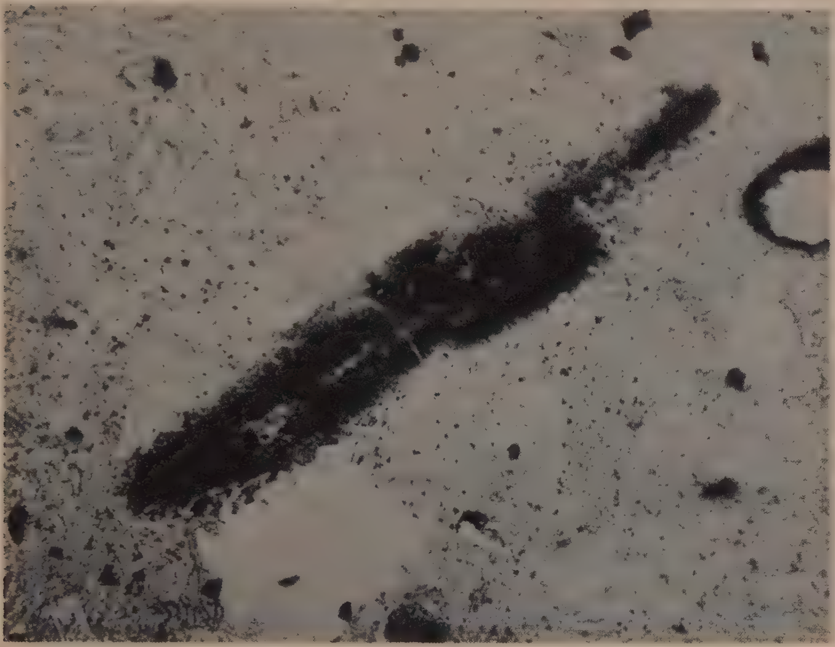

FIG. 9. Hornblende partly resorbed and nearly opaque from dust of iron oxide. Some brown hornblende remains in the lower left-hand part. Photomicrograph in plane-polarized light of Conejos andesite (SV 113) from Summitville quadrangle near head of Alamosa Creek and one mile southeast of Summit Peak. 40×.

	Brown DN 3005	Green SC 2838	Green DN 2017
Or	6.1	5.0	6.1
Ab	11.5	17.2	11.5
An	11.4	19.2	16.4
di	33.0	28.5	29.5
hy	17.5	30.2	28.6
mg	4.2	7.1	6.9
il	3.9	3.5	3.2
hm	11.2		

Tridymite is probably more abundant in the gas cavities of the rocks in which the hornblende and biotite have been resorbed and the iron oxidized, than in the other rocks.

A study of the norms of the hornblendes tells us, approximately, the minerals that should form from the resorption of hornblende. Accordingly, the norms of the three analyzed hornblendes are given above after recalculating nepheline to albite and olivine to hypersthene, as silica would be furnished by the residual siliceous liquid (groundmass).

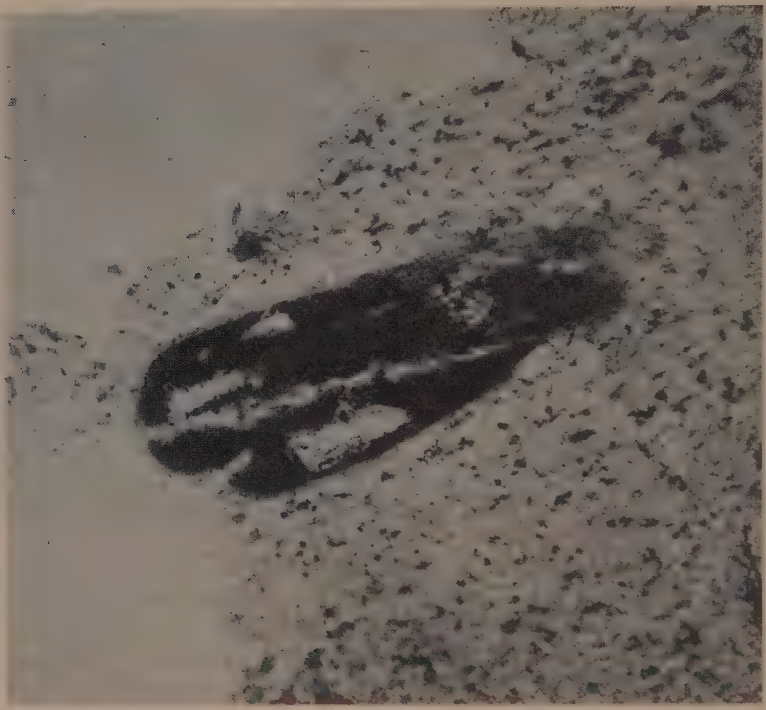

FIG. 10. Hornblende completely replaced by iron oxide. Photomicrograph in plane-polarized light of latite-andesite of lower horizon of the Sheep Mountain andesite (Sa 483). Saguache quadrangle, south slope of Saguache River, about $\frac{1}{4}$ mile below the mouth of Ford Creek at an elevation of 8400 feet. 50×.

The actual minerals formed are feldspar, pyroxene and iron ore. The feldspar is more sodic than that calculated from the hornblende and has no doubt had material from the groundmass added. The pyroxene is mostly diopside but some hypersthene is also formed. Probably some adjustment between the hornblende and the groundmass would be required to furnish lime for the diopside, but the amount would be small.

CONDITIONS THAT DETERMINE WHETHER PYROXENE OR HORNBLENDE SHALL CRYSTALLIZE

Recently Kennedy[25] has discussed the conditions under which hornblende crystallizes from igneous rocks, and concluded that when the MgO-CaO-FeO ratio falls in the field where a homogeneous pyroxene cannot form, hornblende is favored. The three analyzed amphiboles from the San Juan Region fall in the hornblende field of Kennedy. However, several facts observed in the San Juan Region seem to show that composition is not the dominant factor determining the formation of hornblende.

1. Many of the hornblende-bearing rocks carry both diopside and hypersthene.
2. The pyroxene andesites and quartz latites grade into the hornblende rocks and many of the pyroxene rocks contain diopside and hypersthene in such proportions as to fall in the hornblende field.
3. Excepting the rocks with less than 53 per cent of SiO_2, there appears to be no connection between the presence of hornblende or pyroxene and the chemical composition of the rock. Hornblende and pyroxene rocks fall on the same variation diagram. Both hornblende and pyroxene rocks commonly have both diopside and hypersthene in the norm, though a few lack hypersthene and have wollastonite.
4. Resorption of hornblende is almost invariable in the lavas and shallow intrusives, unless cooling was rapid. Pyroxene is invariably formed as a result of this resorption. Pyroxene in rocks lacking all direct evidence of hornblende is formed from the resorption of hornblende.
5. The clinopyroxene of the rocks within the compositional range in which hornblende is found carries little clinohypersthene. The excess (Mg,Fe)O goes largely into hypersthene in the andesites and into biotite in the rhyolites and quartz latites.

The conditions that determine whether amphibole or pyroxene are to form in a rock of the composition of a quartz latite must be either physical conditions of crystallization (such as pressure) or concentration of the minor constituents (such as the mineralizers). The presence of amphibole and biotite in the gas cavities of the lavas of the San Juan and their common occurrence in many shallow hydrothermal deposits in other places seems to eliminate pressure as a determining condition, but fit well with the conclusion that abundance of mineralizers determines the formation of amphibole and biotite. The fact that both amphiboles and biotites are hydrous minerals, while the pyroxenes are anhydrous, fits this explanation.

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[25] Kennedy, W. Q., The influence of chemical factors on the crystallization of hornblende in igneous rocks: *Mineral. Mag.*, vol. **24**, pp. 203–7, 1935.

The history of the crystallization of the magma of the stock south of Piedra Peak is believed to have been about as follows: The magma as erupted to the position where exposed, which was not far from the surface, carried phenocrysts of plagioclase, hornblende, and biotite. The water and other gases escaped, and the hornblende and biotite were no longer in equilibrium with the mineralizer-poor liquid and were resorbed, leaving most of their iron oxide as hematite and magnetite, and precipitating pyroxene, partly at a distance. As the resorption proceeded the pyroxene grains increased in size and finally the hornblende and biotite were completely removed and even the iron ore was moved and recrystallized. The final rock was a granular pyroxene rock with nothing to show that hornblende and biotite had once been the dark minerals.

It will be shown in the following section that both brown basaltic hornblende and common green hornblende are present in the lavas and that the basaltic hornblende differs from the common hornblende only in that the former has little H_2O and most of its iron is in the ferric state. The possibility that the state of oxidation of the iron might determine the formation of hornblende or pyroxene was considered but analyses of series of rocks with hornblende, and of other series with pyroxene, show no apparent difference in the state of oxidation of the iron even though the hornblendes are much higher in ferric oxide than are the pyroxenes.

DESCRIPTION

The amphiboles of the lavas are in part typical brown basaltic hornblende, in part common green hornblende. Those in the andesitic rocks tend to be basaltic, while those in the rhyolites are all common hornblende. The type of the hornblende does not depend entirely on the bulk composition of the rock. In the Alboroto lavas some of the quartz latites have basaltic hornblende while others have common green hornblende, yet the two types of rock are otherwise practically identical in the proportion and character of the phenocrysts and of the groundmass. A basaltic and a common hornblende from two such similar Alboroto latites have been analyzed and studied. One is a typical green hornblende, the other a typical basaltic hornblende, and the only important chemical difference is in the state of oxidation of the iron. The analyses (by F. A. Gonyer) and other properties of these hornblendes, together with one from an andesite dike, are given in Table 4.

TABLE 4. ANALYSES AND PROPERTIES OF AMPHIBOLES FROM THE SAN JUAN REGION, COLORADO

	1 DN 3005	1*a* free of apatite	2 C 2017	2*a* free of apatite	3 SC 2838
SiO_2	44.34	45.17	45.44	46.12	43.95
TiO_2	2.08	2.11	1.67	1.70	1.81
Al_2O_3	7.55	7.68	9.41	9.60	11.40
Fe_2O_3	14.04	14.30	4.81	4.91	4.69
FeO	2.77	2.81	8.97	9.15	9.02
MnO	0.41	0.41	0.34	0.34	0.14
MgO	13.21	13.44	13.04	13.29	13.73
CaO	11.96	11.18	11.71	11.13	11.12
Na_2O	1.35	1.35	1.34	1.37	2.08
K_2O	1.07	1.09	1.06	1.08	0.86
H_2O-	0.06	0.06	0.19	0.19	
H_2O+	0.19	0.19	0.63	0.65	0.79
P_2O_5	0.79		0.71		
F	0.35	0.35	0.80	0.80	n.d.
	100.17	100.14	100.12	100.33	99.59
Less O for F	0.14	0.14	0.33	0.33	
	100.03	100.00	99.79	100.00	
G.	3.246		3.188		

Atomic Ratios (O=24)

	1	2	3
Si	0.668	0.679	0.653
Al	0.135	0.166	0.197
Ti	0.024	0.018	0.021
Fe'''	0.160	0.054	0.055
$Fe''+Mg+Mn$	0.338	0.408	0.418
Ca	0.178	0.173	0.176
Na	0.060	0.060	0.075
H	0.043	0.082	0.079
F	0.017	0.040	n.d.

Optical Properties

	1	2	3	4	5	6	7
				SC 906	Lag 1021	Con A	
α	1.675	1.652	1.658	1.640	1.671	1.69	1.612
β	1.715	1.675	1.673	1.653	1.684		1.622
γ	1.735	1.680	1.683	1.665	1.695	1.76	1.633
Opt. Char.	—	—	—	—	—		
2V	Large	med. large	large	near 90°			near 90°
Disp.	$r<v$ rather	$r<v$ easily		$r<v$ easily			

	strong	perc.		perc.			
Pleochroism							
$\alpha=$	Pale yellow	Pale yellow	Pale yellow brown	Paler than 3	Paler than 1	Darker than 1	Colorless
$\beta=$	Rather dark chestnut brown	Greenish brown	Light brown	Paler than 3	Paler than 1	Darker than 1	Colorless
$\gamma=$	Dark chestnut brown	Olive green	Dark olive brown	Paler than 3	Paler than 1	Darker than 1	Colorless
$\gamma\wedge c$	5°	$14\frac{1}{2}$°	$13\frac{1}{2}$°	$18\frac{1}{2}$°	7°	3°	25°

1. Basaltic hornblende from Alboroto quartz latite (DN 3005), rock quarry about 8 miles southeast of Del Norte, on slope north of Dry Gulch.

1*a*. Analysis 1 computed free of apatite.

2. Green hornblende from Alboroto quartz latite (C 2017). Cochetopa quadrangle, Sheep Creek, near mouth of Bear Creek.

2*a*. Analysis 2 computed free of apatite.

3. Green hornblende from an andesite dike cutting Potosi volcanics at an elevation of 12,000 feet on the east side of the peak with an elevation of 12,880 feet near the southeast corner of the San Cristobal quadrangle.

4. Green hornblende from Hinsdale rhyolite (SC 906) from the northeastern part of San Cristobal quadrangle at the head of Big Spring Gulch along road between Creede and Lake City.

5. Pale brown hornblende from Fisher quartz latite (Lag 1021) in Creede quadrangle, north of Rio Grande, between Farmers and Bellows Creeks, draw on west slope of hill 9740 elevation, at 9100 feet elevation.

6. Basaltic hornblende from Los Pinos quartz latite (Con A) from northeast slope of Green Mountain in the extreme northern part of the Conejos quadrangle.

7. Cotton-like needles of amphibole in the gas cavities of the andesite of the Hinsdale andesite volcanic dome of Cerro Aire, New Mexico, about 4 miles east of No. Agua, New Mexico. The amphibole is probably related to soda tremolite. An amphibole from the cavities of the Hinsdale andesite-basalt from Elk Mountain, in the Creede quadrangle, has $\alpha=1.63$, brownish, $\gamma=1.645$, greenish brown, $Z\wedge c=13°$.

There appears to be every gradation between typical basaltic hornblende and common green hornblende. The optical data in column 4 indicates a hornblende with less Fe_2O_3 than that of columns 2 and 3, that of column 5 is intermediate between 1 and 2, and 6 is even richer in Fe_2O_3 than 1.

All three analyzed hornblendes fit the formula for the amphiboles $(Ca,Na)_2(Na)_{0-1}(Mg,Fe'')_1(Mg,Fe'', Fe''',Al)_4(Al,Si)_2Si_6O_{22}(O,OH,F)_2$. All are rather low in Si, high in total iron, moderate in alkalies, and low in OH+F.[26]

No basaltic hornblende was found in the obsidians or other rocks with rhyolitic glass, but hornblende is rare in rocks so rich in silica as these

[26] Kawano, Y., Chemical formula of basaltic hornblende: *Proc. Imp. Acad. Japan*, vol. **10**, pp. 349–352, 1934.

glasses. In the glassy rocks the biotite and hornblende phenocrysts are less resorbed and iron stained than in the crystalline lavas. In no rocks were both types of hornblende found together, nor was anything seen to indicate that one is derived from the other. However, in the quartz latites of the Highwood Mountains of Montana, the original brown basaltic hornblende is replaced to all degrees by a common green hornblende. The replacement is probably hydrothermal or very late magmatic.

Two specimens of Los Pinos quartz latite are especially instructive. Both were collected from the northeast slope of Green Mountain in the northern part of the Conejos quadrangle. The rocks are very much alike except for the groundmass. Both rocks have abundant large phenocrysts of andesine and biotite and fewer of hornblende, pyroxene and magnetite. One has a gray, glassy groundmass, the other a reddish-brown microcrystalline groundmass. The rock with a glassy groundmass has more phenocrysts of plagioclase and biotite and fewer of diopside than the one with a crystalline groundmass.

Chemically, the two rocks are very similar, the chief differences being that the glassy rock has one per cent more water and $1\frac{1}{2}$ per cent more FeO, and correspondingly less Fe_2O_3, than the holocrystalline rock. The glassy rock has a common green hornblende ($\gamma=1.68$) and a biotite with $\gamma=1.655$, neither of which show appreciable resorption, while the holocrystalline rock has a dark brown basaltic hornblende ($\gamma=1.76$), and a biotite with $\gamma=1.723$, both of which show much resorption.

Kôzu and Yoshiki[27] have shown that two quartz andesites from the volcano Sambé, Japan, are very similar except for color, and that the red-brown lava has basaltic hornblende and high index biotite, while the gray lava has green hornblende and low index biotite.

A statistical study of 20 analyzed San Juan lavas that contain hornblende—listed below—show no appreciable tendency for basaltic hornblende to be concentrated either in the red or brownish rocks.

TYPE OF HORNBLENDE

Color of Rock	Basaltic	Common pale brown	Green
Gray to black	5	2	2
Reddish gray	1		1
Red and brown	4	3	1
Nearly white	1		1

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[27] Kôzu, S. and Yoshiki, B., Thermo-optic studies of anomite-basaltic hornblende-quartz-andesite in association with biotite-common hornblende-quartz-andesite, which together form the volcano Sambé in Japan: *Science Reports, Tôhoku Imp. Univ., Ser.* III, vol. 3, pp. 180–193, 1929.

None of the five rocks with rhyolitic glass had basaltic hornblende, but such hornblende is rare in rocks of the composition of these. The biotite associated with the basaltic hornblende in every case has an index of refraction (γ) greater than 1.70, while all the light brown or green hornblendes are associated with a biotite with γ less than 1.67. There appears to be little difference in the extent of the resorption in the two types of hornblende. The hornblendes in the andesitic rocks are in nearly all cases basaltic, those in the quartz latites are divided between the three types, and those of the rhyolites are nearly all green.

CONDITIONS UNDER WHICH BASALTIC AND COMMON HORNBLENDE FORM

Kôzu, Yoshiki, and Kani[28] have shown that common hornblende heated to 750°C. changed to brown basaltic hornblende and that the change is caused by a loss of H_2O and oxidation of the iron. The fact that in the San Juan lavas the basaltic hornblende tends to be in the high-temperature andesites and absent in the low-temperature rhyolites may give some clue as to the temperature range of the magmas.

The evidence from the San Juan lavas indicates that temperature is not the only condition that determines the kind of hornblende formed, since lavas of essentially the same character, over a wide range of composition, may have either kind of hornblende. As shown by the amphibole formula

$$(Na, Ca)_{2-3}(Mg, Al, Fe'', Fe''')_5(Si, Al)_8O_{22}(OH, F, O)_2$$

if Fe'' is replaced by Fe''' some replacement, such as OH by O, must take place, and the analyses bear this out. Hence, the oxidation of iron in an amphibole should be accompanied by a loss of H.

6. BIOTITE

BY ESPER S. LARSEN, F. A. GONYER, AND JOHN IRVING

DESCRIPTION

Biotite is practically absent from the basalts and pyroxene andesites of the San Juan area. As the rocks increase in silica content, biotite begins to make its appearance at about the same composition as free silica (58% SiO_2), in the latite-andesites, and it is present in nearly all the rocks with more than that amount of SiO_2. In the less siliceous rocks it is subordinate to the other mafic minerals but as the rocks become richer in silica and alkalic feldspar, biotite constitutes a larger proportion of the mafic minerals; and in most of the rocks with over 60% of SiO_2 it is the chief, and in many rocks the only mafic mineral. However, as the proportion of mafic minerals decreases rapidly as the silica increases, the total amount of biotite is greatest in the quartz latites. Biotite comprises only a few per cent of most rocks, but it slightly exceeds 10 per cent in a few.

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[28] Kôzu, S. Yoshiki, B., and Kani, K., Note on the study of the transformation of common hornblende into basaltic hornblende at 750°C.: *Science Reports, Tôhoku Imp. Univ., Ser.* **III**, vol. 3, pp. 143–159, 1927.

Kôzu, S. and Yoshiki, B., The dissociation temperature of brown hornblende and its rapid expansion at this temperature: *Science Reports of Tôhoku Imp. Univ., Ser.* **III**, vol. 3, pp. 107–117, 1927.

Biotite is present also in many of the granular intrusive rocks, even in the gabbros, but it is usually in small amount. In the gabbros it is a very late mineral to crystallize, while in the granites it is one of the early crystals. Light-colored biotite is rather common as a high-temperature hydrothermal mineral.

Biotite is commonly associated with quartz and alkali feldspar, except in some of the gabbros. It is commonly associated with hornblende, among the mafic minerals, less commonly with pyroxene where hornblende is lacking. It was not found in effusive rocks that contain olivine.

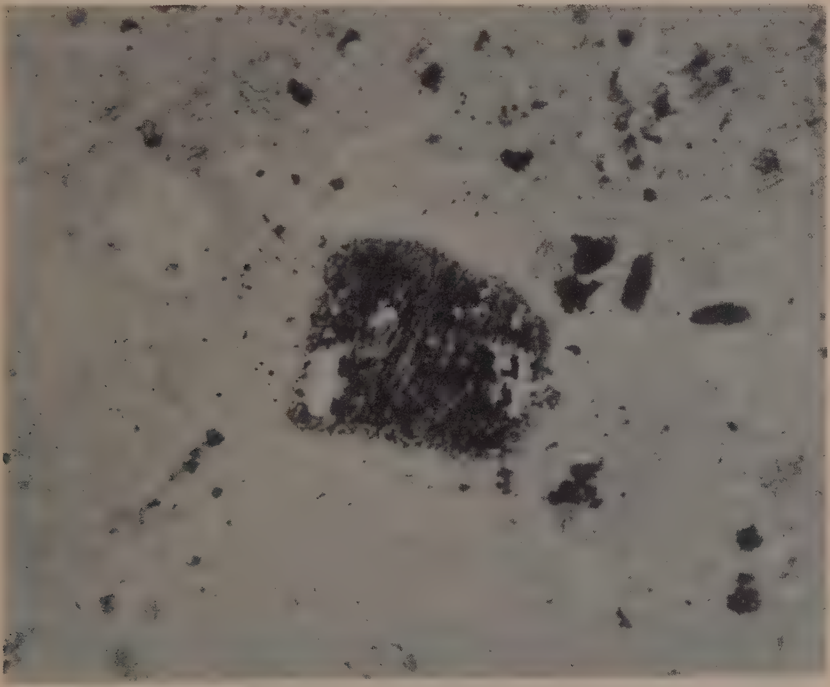

Fig. 11. Biotite with resorption and development of pyroxene and other minerals about the border, and with some iron in the main part of the crystals, but otherwise fresh. Fisher latite-andesite (SC 1663)—northeastern part of the San Cristobal quadrangle, near head of Mineral Creek on west side at an elevation of 11,400 feet. 45×.

RESORPTION

The biotites of the extrusive rocks commonly show resorption and, while the extent of the resorption varies greatly in rocks of the same composition, on the average it is greater in the less siliceous rocks, and may be almost entirely lacking in the rhyolites. All stages in the resorption have been followed from slight reaction on the borders to complete removal, leaving only a dust of iron oxide to show the original presence of biotite. In the earliest stage of the resorption, the borders of the grains are frayed and are more deeply colored. Pyroxene or a reddish alteration product in tiny prisms, or as a lacework, are concentrated next to the border. Grains of iron ore are scattered through the biotite and parts of the biotite are bleached. On further resorption an outer zone of the biotite is replaced by fine-grained feldspar, red and black ore, and pyroxene; and the inner part is biotite with grains of red and black ore. At a later stage all the biotite is replaced. In some a little pale biotite is formed and rarely epidote or piedmontite. Finally, all evidence of the original biotite is destroyed. Three types of the resorption are shown in Figs. 11, 12, and 13.

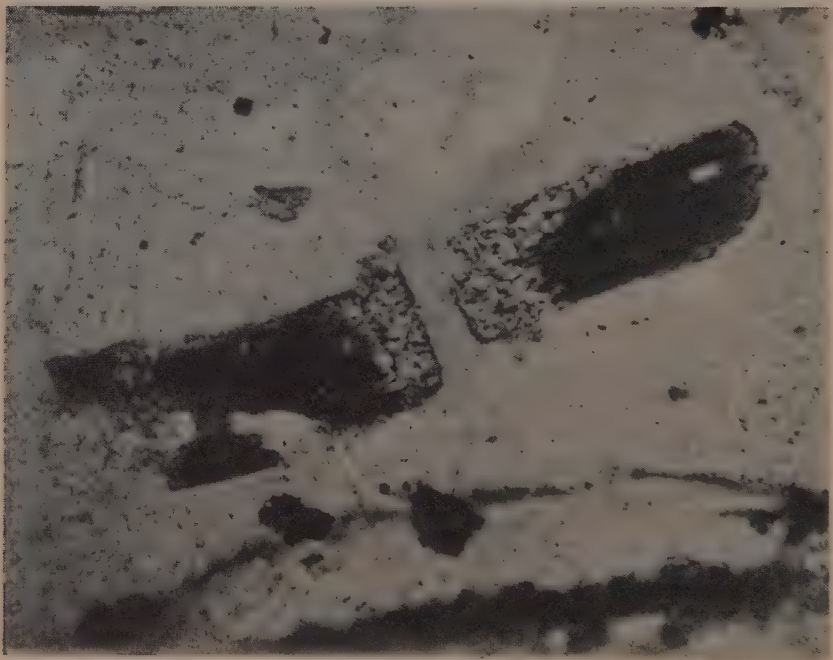

FIG. 12. Two biotite crystals resorbed to a dust of iron oxide, pyroxene, etc., in the central part of the figure but fresh except for a little iron stain to the right and left. Fisher latite-andesite, northern part of San Cristobal quadrangle, west of Lake San Cristobal on ridge south of Grassy Mountain, at an elevation of 11,400 feet. 45×.

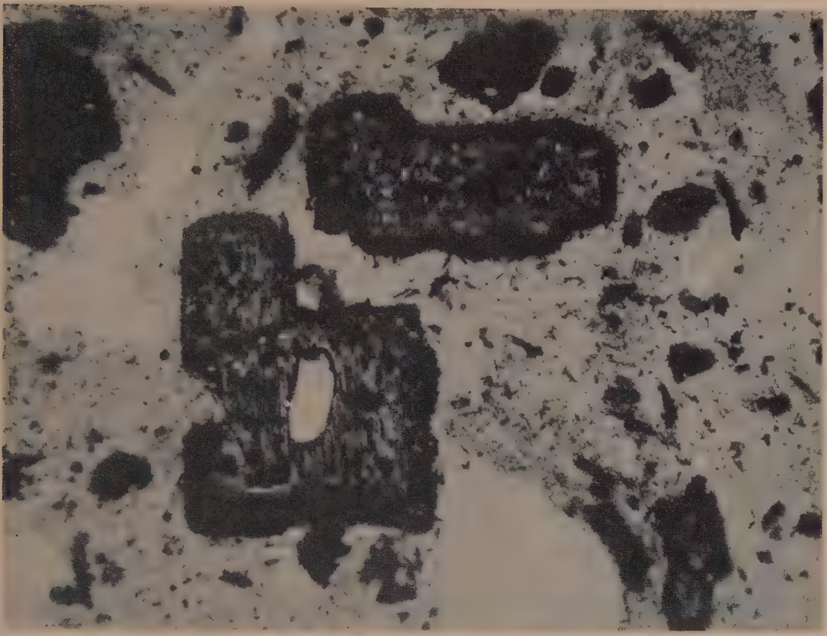

FIG. 13. Two biotite crystals with opaque reaction rims and opaque ore scattered throughout the main parts of the crystals. Fisher latite-andesite (SV 1315) from northern part of San Cristobal quadrangle, north of Cascade Gulch and on northwest slope of hill with 13,100 contour at 13,100 feet elevation. 45×.

DESCRIPTION

The biotites of the extrusive rocks have variable indices of refraction which, except in a few rhyolites, are considerably higher than those of the granular rocks. The value of γ has been measured for nearly all of the biotites of the analyzed extrusive rocks, and is plotted against the position in the plots used in the chemistry and the approximate SiO_2 content in Fig. 14. The values of γ vary from 1.63 to 1.73. They fall into three groups with a few intermediate values. A group in which γ varies from 1.70 to 1.73 includes nearly all the biotites from the less siliceous rocks—latite-andesites—and nearly half of those from the quartz latites, but few from the rhyolites. Another group in which γ ranges from 1.65 to 1.68 includes the biotites from most of the rocks with moderate silica content. A third group, in which γ ranges from 1.63 to 1.64, includes most of the biotites from the highly siliceous rhyolite.

A fourth group includes biotite in the granular rocks, whether gabbro or granite. The crystals are free from resorption, are light colored, have very small 2V, considerable dispersion ($r<v$) and indices of refraction (β) ranging in five specimens from 1.629 to 1.641. They are believed to

be low in Fe_2O_3. Similar biotites are present in small amounts in the gas cavities and porous parts of some of the lavas where they are associated with tridymite. Biotites of this group are not included in the plot.

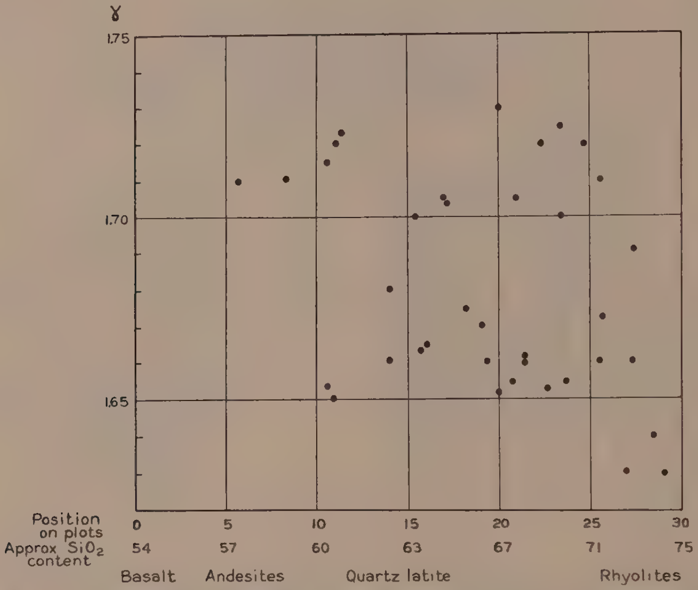

FIG. 14. The index of refraction (γ) of the biotites of the analyzed extrusive rocks of the San Juan Region, Colorado, plotted against the composition of the rock in which they occur.

All of the biotites studied have strong dispersion of the optic axes with $r<v$. The axial angles are rather variable and are unusually large for biotite. Those with low indices of refraction have smaller axial angles, and those with γ near 1.63 have the very small angle common in biotite.

Four of the biotites have been analyzed by F. A. Gonyer and their analyses and optical properties are given in Table 5.

TABLE 5. ANALYSES AND OPTICAL PROPERTIES OF BIOTITES FROM THE SAN JUAN LAVAS

	1 SC xx	2 C 2017	3 DN 3006	4 Con A
SiO_2	38.56	39.14	39.25	37.24
TiO_2	4.95	4.27	3.63	4.19
Al_2O_3	14.12	13.10	12.90	14.14
Fe_2O_3	5.51	12.94	17.13	17.71
FeO	8.25	5.05	1.85	0.53
MnO	0.20	0.14	0.23	0.07

MgO	15.59	12.75	12.91	13.81
CaO	1.06	1.64	1.97	0.87
BaO	0.43	—	0.41	—
SrO	none	—	none	—
Na_2O	0.81	0.70	1.10	0.68
K_2O	8.68	6.55	6.87	6.36
H_2O-	—	0.58	—	—
H_2O+	1.03	2.41	1.32	0.63
F	1.25	1.11	1.01	0.37
	100.44	100.38	100.58	96.60[29]
Less O for F	0.53	0.46	0.43	
	99.91	99.92	100.15	
G.	2.984	2.862		

Ratios in Biotite formula[30] $W_4(X, Y)_{12}(Z_{16}O_{40})(O, OH, F)_2$
$W = K$, Na, little Ca
$X = Mg, Fe, Mn, Ti$
$Y = Al, Fe'''(Ti)$
$Z = Si:Al \geq 5:3$

(K, Na, Ca)	4.2	3.4	4.0	3.1
(Mg, Fe'')	9.1	7.0	6.4	6.5
Ti	1.1	1.0	0.8	1.0
(Al, Fe''')	6.3	7.5	8.5	9.2
Si	11.6	11.6	11.8	11.4
O	44.8	42.0	45.0	46.0
(OH, F)	3.2	6.0	3.0	2.0
α	1.592±0.005	1.594	1.605±0.01	1.610
β	1.650	1.671	1.716	1.722
γ	1.651	1.672	1.720	1.723
$2E_{Na}$ range	36 to 59°	16 to 43°	35 to 61°	33 to 54°
$2E_{Na}$ average	52°	26°	47°	48°
Total Fe (as FeO)+MnO	13.40	16.84	17.50	16.54
SiO_2 content of rock	71	66½	67	60

1. (SC xx) From Piedra rhyolite glass, eastern part of San Cristobal quadrangle, road north of Rio Grande and 1 mile east of Clear Creek.

2. (C 2017) From Alboroto latite (has green hornblende, see analysis 2 of the hornblendes), Cochetopa quadrangle, Sheep Creek near mouth of Bear Creek.

3. (DN 3006) From Treasure Mountain latite (has augite but no hornblende), Del Norte quadrangle, 5 miles southeast of Del Norte, north fork of gulch between Lime and Raton Gulches, ¼ mile from lower contact of Treasure Mountain formation.

4. (Con A) From Los Pinos andesite-latite (is red in color and has basaltic hornblende, optical data 6 of hornblendes). Northeast slope of Green Ridge in the extreme northern part of Conejos quadrangle.

[29] Sample probably retained a little bromoform from heavy liquid separation.

[30] After Harry Berman, personal communication.

The analyses show that the difference chemically between the biotites with high indices of refraction and those with low indices of refraction is chiefly in the state of oxidation of the iron, which is almost entirely ferric in the high index minerals. The OH+F may be lower in the high index biotites. Analysis 1 is also lower in total iron and higher in MgO.

The biotites with high indices of refraction (>1.70) are associated with dark brown basaltic hornblende; those with intermediate indices (1.66 to 1.70) are associated with light brown, less commonly green hornblende; and those with low indices (<1.66) are associated with green hornblende. Hence high Fe_2O_3 biotite and high Fe_2O_3 hornblende form under about the same conditions. Possibly biotite is a little more readily oxidized. Kôzu and Yoshiki[31] have shown that the two kinds of biotite are in different lavas of Sambé volcano and have studied the change in low index biotite on heating. They found that on heating, the γ index of refraction changed from 1.655 to 1.703, and the axial angle, 2E, from 38.4° to 48.5°. The change takes place gradually and mostly between the temperatures 500° to 800°. In the rocks, they found a low index of refraction for the hornblende and biotite in bread-crust bombs, somewhat higher values for the minerals in a gray andesite, and very high values for those in a red andesite. Their values are given below.

Hornblendes

	Bread-crust bomb	Gray andesite	Red andesite
α' on cleavage	1.661	1.675	1.692
γ' on cleavage	1.673	1.685	1.707
Ext. on cleavage	17°	11°	ca. 0°
α	Pale green	Light brownish yellow	Yellowish green
β	Green	Brownish yellow	Brown
γ	Bright green	Greenish brown	Dark reddish brown
FeO content		10.97	7.69
Loss ign.		0.23	0.08

Biotites

	Bread-crust bomb	Gray andesite	Red andesite
α		1.589	1.597
γ	1.641	1.655	1.703
2E	near 0°	38.4°	41.7°
FeO content		10.32	5.96
Loss ign.		2.76	1.53

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[31] Kôzu, S. and Yoshiki, B., Thermo-optic studies of anomite-basaltic hornblende-quartz-andesite in association with biotite-common hornblende-quartz-andesite, which together form the volcano Sambé, Japan: *Sci. Reports Tôhoku Imperial University, Ser.* **III,** vol. 3, pp. 177–193, 1929.

CONCLUSIONS

(1) In part, the character of the hornblende and biotite is determined before the final eruption of the lava, but probably after it has reached a position near the surface. In considerable part the change from common to basaltic hornblende, and from low to high ferric iron biotite, takes place after eruption and during the crystallization of the groundmass.

(2) High Fe_2O_3 and low H_2O in both hornblende (basaltic) and biotite are more common in rocks at the andesitic end of the series and were not found in rocks near the extreme rhyolitic end.

(3) The conditions favoring the formation of Fe_2O_3-rich hornblende and biotite are probably approximately expressed by the mass action equation: $2FeO+H_2O \rightleftarrows Fe_2O_3+2H$, and the geological conditions are probably temperature, sufficient H_2O concentration, and escape of H as formed.

(4) Probably the same conditions favor the oxidation of the iron in lavas near the vents and in the crystalline parts of flows. This oxidation is not common in basaltic rocks, except as expressed by the replacement of olivine by iddingsite. The hydrogen of volcanic gases is at least in part derived from the reaction of H_2O on FeO near the surface.

(5) The resorption of hornblende and biotite is favored by near-surface conditions; it may begin before the magma is erupted to the surface but much of it takes place after eruption. It is somewhat more common in rocks near the andesites in composition than in those near the rhyolites.

(6) The material of the hornblende, after resorption, goes chiefly into iron ore, feldspar and pyroxene; the pyroxene being much lower in total iron than the hornblende. The resorption of biotite yields feldspar as well as iron ore and pyroxene.

(7) The condition that favors the crystallization of hornblende and biotite rather than pyroxene from a magma is probably abundance of mineralizers.

OCTAHEDRAL PARTING ON GALENA FROM BOULDER COUNTY, COLORADO

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Introduction

Octahedral parting or cleavage has been noted on galena from comparatively few localities. It is of interest because it offers a distinct contrast to the perfect cubical cleavage ordinarily observed on galena. The cause of the octahedral splitting has been more or less a subject of controversy; several different theories have been proposed to account for the phenomenon.

The literature on the subject prior to 1904 has been reviewed by Hintze,[1] according to whom galena with octahedral cleavage has been described from Vermland, Sweden, by Sjögren,[2] and from Lebanon County, Pennsylvania, by Cooke.[3] The galena from both places is changed upon heating, so that it displays only cubical cleavage. Galena from Habach with a difficult octahedral cleavage developed a pronounced cleavage after heating, according to Zepharovich.[4]

Some writers have suggested that octahedral cleavage results from polysynthetic twinning in galena; others, as for example Cooke,[5] believe that it is caused by pressure. Torrey[6] suggested that the galena is pseudomorphous after some mineral with an octahedral cleavage, or that it is a dimorphous form of galena. Sjögren suggested that the octahedral cleavage is related to the bismuth content that has been found in several analyzed specimens. His suggestion seems to be supported by the following analyses listed by Dana:[7] Habach, Salzburg, Bi_2S_3, 1.97%; Mont Blanc, Bi_2S_3, 1.0%; Nordmark, Sweden, Bi_2S_3, 0.91%.

Although early writers used the term "cleavage" to describe this splitting, recent textbooks describe it as "parting." Niggli[8] uses the term "parting" and ascribes it to systematically oriented crystal inclusions of bismuthinite in the galena. In the opinion of the present writer, Niggli's explanation probably applies to most of the known examples of bismuth-bearing galena with octahedral parting.

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[1] Hintze, Carl, *Handbuch der Mineralogie*, vol. **1**, Part I, p. 461, 1904.
[2] Sjögren, H., *Geol. För. Förh.*, vol. **7**, p. 124, 1884.
[3] Cooke, J. P., *Am. Jour. Sci.*, vol. **35**, p. 126, 1863.
[4] Zepharovich, V., *Zeits. Krist.*, vol. **1**, p. 156.
[5] Cooke, J. P., *op. cit.*
[6] Torrey, J., *Am. Jour. Sci.*, vol. **35**, p. 127, 1863.
[7] Dana, *System of Mineralogy*, 6th Edition, p. 49, **1915**.
[8] Niggli, P., *Lehrbuch der Mineralogie*, Pt. **2**, p. 52, 1926.

Occurrence and Mineralogy of the Galena

The galena described in this paper is found in the hypothermal veins at Camp Albion, Boulder County, Colorado, associated with pyrite, chalcopyrite, sphalerite, and minor amounts of molybdenite. Gangue minerals are quartz, fluorite, feldspar, calcite, soda asbestos, and diopsidic aegirite. The veins occupy a fracture zone cutting the contact between a series of pre-Cambrian schists and gneisses, and a composite Tertiary igneous stock of monzonite and syenite. The veins have formed by fracture filling and by irregular replacement of the wall rocks of the fractures.

The proportions of metallic and gangue minerals vary considerably from place to place within a single vein, and from one vein to another. The galena is found most abundantly in the Snowy Range Mine in which a vein consisting chiefly of pyroxene and asbestos contains small scattered interstitial aggregates of galena. These aggregates display excellent, closely-spaced octahedral parting planes, with no indication of a cubical cleavage. The angles between the parting surfaces were measured with a reflecting goniometer and proved to be characteristically octahedral.

In a nearby mine, the Eureka, another vein containing large amounts of quartz and calcite, in addition to the pyroxene and asbestos, yielded galena with ordinary cubical cleavage. Inasmuch as the vein is genetically related to that in the Snowy Range Mine, it was thought desirable to analyze specimens from both veins in order to test the theory that the presence of bismuth may explain the octahedral parting. Analyses of the two types of galena from Camp Albion and two analyses of galena from other localities follow:

	I	II	III	IV
Pb	81.92	81.40	84.59	85.67
Bi	1.36	1.12	1.59	0.76
Zn	1.19	0.96	—	—
Ag	0.22[1]	0.12[1]	—	0.05
Fe	—	—	—	0.39
S	13.53[2]	13.25[2]	13.52[2]	13.59
Te	0.45	0.41	—	—
Insol. Impurity	1.30	1.32	—	—
Sol. Impurity	—	1.42[3]	—	—
	99.97	100.00	100.00	100.46

[1] Silver by cupellation.

[2] Calculated.

[3] Chiefly calcite; by difference.

I. Galena with octahedral parting, Snowy Range Mine, Boulder County, Colorado. Analyst: E. E. Wahlstrom.
II. Galena with cubical cleavage, Eureka Mine, Camp Albion, Boulder County, Colorado. Analyst: E. E. Wahlstrom.
III. Galena with octahedral parting, Habach, Salzburg; described by v. Zepharovich. Analyst: Weselsky.
IV. Galena with octahedral parting; described by Sjögren. Analyst: Wallroth.

The impurities in the analyzed specimens were found microscopically to consist of mechanically intermixed gangue minerals and sphalerite. Upon correcting for impurities and allotting tellurium to bismuth to form tetradymite, the following percentages of mineral molecules were obtained:

	I	II
PbS	97.49	98.08
Ag_2S	0.36	0.15
$Bi_2(S, Te)_3$	2.15	1.77
	100.00%	100.00%

An inspection of the analyses shows that the two types of galena from Camp Albion are chemically nearly equivalent. This similarity of composition is offered as proof that bismuth-bearing galena may or may not have an octahedral parting, and that other factors must be considered in explaining the phenomenon. The percentages of bismuth come well within the upper and lower limits of bismuth in analyzed specimens of galena with octahedral parting from other localities.

Polished Section Data

A study of several polished sections of the ores was made to obtain further information bearing on the problem. It was determined that the parting planes are controlled by tetradymite inclusions which are oriented in closely spaced laminae paralleling the octahedral directions of the galena. The tetradymite laminae are about .005 mm. thick and spaced, on the average, about 0.2 mm. apart; the mineral cannot be observed until the polished surface has been etched. A geometrical pattern consisting of polygons formed by the traces of intersecting layers then stands out in strong relief. The shapes of the polygons are determined by the direction of the surface of the polished section with reference to the octahedral planes. The polygons most frequently seen are either triangular or quadrilateral.

It should be emphasized that on the polished surface the tetradymite forms regularly-spaced continuous lines of uniform width and does not form lenticular linear structures such as are frequently observed in bornite-chalcocite intergrowths or in hematite-magnetite mixtures as recently described by Greig, Merwin, and Posnjak.[9] The uniform distribution of tle tetradymite and the lack of structures that might be interpreted as of replacement origin suggest that the tetradymite layers are formed by exsolution. This conclusion is substantiated by the chemical analyses given above, which show that the bismuth content does not vary greatly from specimen to specimen, despite the fact that the specimens are found in different veins and outwardly have a different appearance.

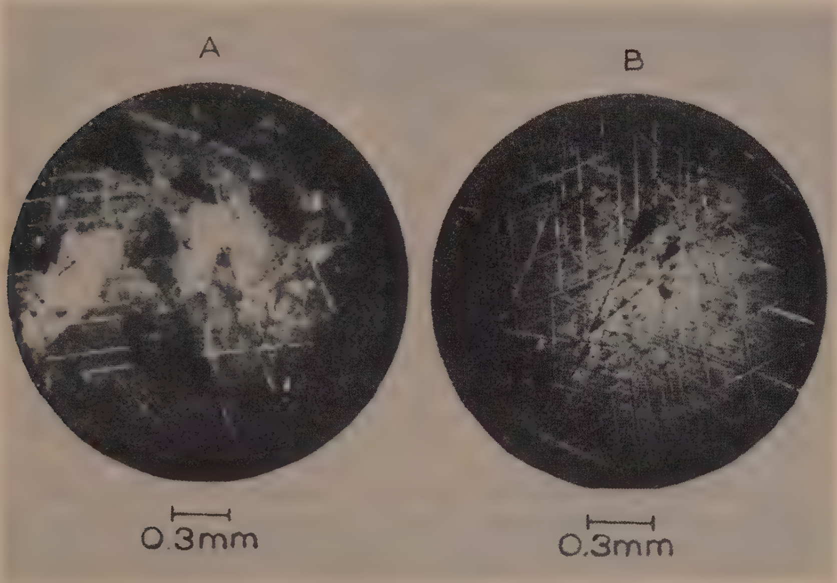

FIG. 1. A. $FeCl_3$ etched polished surface of galena with octahedral parting from Camp Albion, Boulder County, Colorado. The white lines are the traces of tetradymite plates which parallel the octahedral directions of the galena. The black triangular figures are pits formed during grinding; these are controlled by the tetradymite plates.

B. $FeCl_3$ etched polished surface of galena with cubical cleavage from Eureka Mine, Camp Albion, Boulder County, Colorado. The lines are the traces of tetradymite plates which parallel the octahedral directions of the galena. The small triangular patches are pits controlled by cubical cleavage. The sides of the pits do not parallel the tetradymite plates as in Figure 1A.

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[9] Greig, J. W., Merwin, H. E., and Posnjak, E. Separation planes in magnetite: *Am. Mineral.*, vol. **21**, p. 504, 1936.

The exsolved tetradymite is found in both types of galena. In polished sections of the galena with octahedral parting the sides of the polygons parallel the sides of the pits formed by the breaking out of pieces of galena during grinding and polishing. In the galena with the cubical cleavage the exsolved plates again parallel the octahedral directions but the pits are in this case controlled mainly by the perfect cleavage, and the tetradymite polygons do not generally coincide with the outlines of the pits. A very few triangular pits which are controlled by the tetradymite layers, as in the type exhibiting only the parting, were observed. Photomicrographs of etched polished sections are shown in Fig. 1.

The observation of the exsolved tetradymite is best made after a brief application of 20% $FeCl_3$ solution or 1:1 HCl. Although the galena and tetradymite give similar etch reactions, the tetradymite is attacked less vigorously by the reagents than the galena, and stands out in relief, if not exposed too long to the etching solutions.

Following are the etch tests obtained from several specimens of both types of galena and the tetradymite.

Galena (cubical and octahedral)	*Tetradymite*
Isotropic	Anisotropic
Hardness B	Hardness B (estimated)
Color: galena white	Color: galena white

Etch tests:

HNO_3	Stains black; fumes tarnish	Stains black with slow effervescence
HCl	Tarnishes iridescent	Slowly tarnishes iridescent
KCN	Neg.	Neg.
$FeCl_3$	Tarnishes iridescent	Slowly tarnishes iridescent
KOH	Neg.	Neg.
$HgCl_2$	Neg.	Slowly tarnishes iridescent

Microchemical tests on small amounts of material reveal the presence of lead only, as it is necessary to use comparatively large amounts of material to obtain positive tests for bismuth and tellurium. For these tests it is best to leach with HCl the residue of a fragment of galena at least 2 mm. in diameter that has been decomposed with 1:1 HNO_3. Selenium is absent.

ORIGIN OF THE PARTING

The fact that the galena from the Snowy Range veins shows only parting, whereas that from the Eureka vein displays a cubical cleavage is not easily explained. It is probable that the galena with the parting is in a metastable state, resulting from peculiar conditions that obtained after precipitation of the minerals from solution. Inasmuch as the two veins from which specimens were collected contain different proportions of gangue minerals, it might be suggested that the chemical environment was the controlling factor in either vein. However, it seems more probable to the writer that mechanical stresses active during or after the ore-forming period account for the observed features. This conclusion is supported by the fact that the galena with the octahedral parting loses this property upon being heated in a closed tube, and changes to a form with cubical cleavage. Apparently the stresses set up in the mineral during heating cause the development of minute fractures along the cube directions. Presumably the change during heating is mechanical and not chemical.

CONCLUSIONS

In summary, the following conclusions have been reached: the octahedral splitting in galena from Camp Albion, Boulder County, Colorado, is parting and not cleavage. The parting is primarily controlled by closely spaced layers of tetradymite which parallel the octahedral directions of the galena. The tetradymite probably formed by exsolution from galena that was originally bismuth-bearing.

A bismuth-bearing galena may show either cubical cleavage, or octahedral parting, or both, depending on the nature of mechanical stresses in the material after precipitation from solution. Probably the galena with octahedral parting is in a metastable state, and if subjected to the proper stresses, it will change to the form ordinarily seen.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to Professors R. D. Crawford and P. G. Worcester who critically read the paper, and to Dr. W. O. Thompson who carefully criticized the manuscript.

COMPOSITION AND STRUCTURE OF STILPNOMELANE

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INTRODUCTION

Stilpnomelane is an iron silicate which has been described from a number of iron mining districts where it occurs usually as a vein mineral, in iron formations, or in iron ore. Lately, however, it has been described from Western Otago, New Zealand (8), as a constituent of chlorite-epidote-albite schists in which it seems to be quite common. It is quite possible that stilpnomelane is much more widely distributed than is generally believed because only very close inspection under the microscope will distinguish it from biotite in fine grained material. This optical resemblance has been emphasized a number of times. In the hand specimens it occurs as curved bladed and micaceous aggregates showing perfect basal cleavage. In color it varies from pitch black through greenish to brownish black. The almost golden brown varieties have been called chalcodite, though structurally they are stilpnomelane, as will be shown. In hardness the mineral resembles the chlorites, though it is much more brittle, possessing no toughness as mica or chlorite. Occasionally "hexagonal" platy basal sections are seen under the microscope. All these properties make it certain that stilpnomelane is a close relative of the chlorites and micas, and therefore, possesses a layer structure. Some doubt was cast on the correctness of some of the layer structures as proposed by the writer by the work of Ksanda and Barth[1] on dickite. Hendricks,[2] however, has confirmed the writer's structure of kaolinite. He also finds[3] that the space group of dickite given by the writer is correct though the structure of the individual layer does not seem to be "quite correct." The structure of vermiculite has also been recalculated once more by the writer and found as published in 1934 (13). It must be admitted, however, that the structure of stilpnomelane is more difficult of interpretation and is solved only in part. Since it contains some very unusual features its publication seems desirable at this time. The writer is indebted to Dr. W. F. Foshag for analyzed samples and to Dr. R. B. Ellestad and Dr. Samuel Goldich for many suggestions in connection with the chemistry of stilpnomelane. The liberal grants of the Graduate School of the University of Minnesota have made this study possible.

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[1] Ksanda, C. J., and Barth, T. F. W., Note on the structure of dickite and other clay minerals: *Am. Mineral.*, vol. **20**, p. 634, 1935.

[2] Hendricks, S. B., Concerning the crystal structure of kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, and the composition of anauxite: *Zeits. Krist.*, vol. **95**, pp. 247–252, 1936.

[3] Personal communication.

TABLE 1. ANALYSES OF STILPNOMELANES AND THEIR AVERAGE COMPOSITION

	1. Theodor Mine	2. Mont Chemin	3. Genoa Mine	4. Baern	5. North Wales	6. West-field	7. Lambert-ville	8. Molecular Ratios	9. No. of Oxide "Molecules"*	10. Total Molecular Weight	11. No. of Positive Ions	12.
SiO_2	44.08	44.70	46.85	44.77	43.74	44.08	45.12	0.7453	32.000	1921.9	32	
Al_2O_3	3.94	5.16	4.64	6.32	6.36	4.74	6.29	0.0525	2.254	229.8	4.5	13.2
Fe_2O_3	13.33	16.38	11.60	20.79	22.47	5.27	23.67	0.1015	4.358	695.9	8.7	
FeO	25.08	15.08	20.00	12.83	15.74	23.31	5.93	0.2346	10.730	770.8	10.1	16.0
MgO	2.00	5.88	5.75	4.01	1.43	8.36	9.36	0.1303	5.595	225.6	5.6	
MnO	0.05	1.15	0.33	0.21	0.50	0.87	tr.	0.0063	0.270	19.1	0.3	
CaO	0.40	0.00	0.94	0.10	0.53	tr.	tr.	0.0050	0.215	12.1	0.2	1.9
Na_2O	0.67	0.84	0.27	0.07			tr.	0.0042	0.180	11.2	0.4	
K_2O	2.20	1.79	2.07	3.31	0.75		tr.	0.0153	0.657	61.9	1.3	
TiO_2	0.05	0.18	0.15	0.04								
H_2O+	6.63	7.17	5.77	5.64	6.36	10.97	9.12	0.3934	16.891	304.4	33.8 H	
H_2O-	1.96	1.83	1.80	1.96	2.59	2.21		0.1142	4.903	88.3	9.8 H	
	100.39	100.23	100.17	100.05	100.47	99.81	99.49					
Gr.	2.823		2.81	2.89	2.85							
Molecular Weight	4374	4300	4101	4294	4419	4356	4235			4341		

* These calculations are based on the assumption that 32 SiO_2 "molecules" are distributed over 4 unit cells.

1. From Theodor Mine. Described in great detail by Holzner (1).

2. From Mont Chemin. Described by Jakob (7).

3. From Genoa Mine of the Mesabi range. Described by Grout and Thiel (6). This occurrence was discovered by the present author in 1921 and the analyzed material was available for the present investigation.

4. From Baern (Sternberg-Bennisch), Moravia. Museum specimen No. 3208 of University of Minnesota. Black color, pitchy to glassy luster. Light greenish brown streak. $\alpha=1.58\pm.01$, $\gamma=1.677\pm.004$, 2 V very small. Analyzed by S. Goldich in the Rock Analysis Laboratory of the University of Minnesota for the present investigation. Originally described by Kretschmer (9).

5. From North Wales. Described by Hallimond (5).

6. From Westfield, Mass. Average of two analyses. Described by Shannon (3). The original analyzed sample No. 93438 of the U. S. National Museum was used in the present investigation.

7. From Lambertville, N.J. Described by Shannon (4) as chalcodite. The original analyzed samples No. 84735 and 84736 of U. S. National Museum were used in this investigation.

8. From a vein at Crystal Falls, Michigan. Unanalyzed material. Kindly furnished by Dr. V. L. Ayres of Houghton, Mich.

CHEMICAL COMPOSITION

Only the most reliable analyses were selected from the literature for the determination of the chemical composition of stilpnomelane. A new analysis was made of the mineral from Baern bringing the total used in this paper to seven. They are recorded in Table 1 and the specimens are described in the accompanying paragraphs.

It will be noticed that the SiO_2 content is remarkably constant, but enormous fluctuations occur in the ratios of Fe_2O_3:FeO. It was this fact which had caused a former division into stilpnomelane and chalcodite, the latter being "oxidized" stilpnomelane. Such a division is untenable on structural grounds. Besides, in a single specimen of apparently homogeneous material this oxide ratio will vary considerably. There has also been discussion as to whether the alkalies are essential constituents. Table 1 shows that they are not necessary though commonly present. CaO structurally is included in the alkalies. Their total average content in the first five analyses is only about one fourth of that which is commonly found in micas. The amount of H_2O, with the exception of No. 6, is fairly uniform. To arrive at a chemical formula for the mineral the molecular ratios were computed for each occurrence. From these the number of oxide molecules were calculated on the basis of 32 SiO_2 for a unit volume. This number was chosen because it represents an approximation to the largest possible number of SiO_2 in four unit cells as will be shown. Also the theoretical proportional molecular weights for these unit volumes were computed and are found in the bottom row of Table 1. Table 2 lists the proportional numbers and kinds of positive ions in unit volumes containing these molecular weights. In the second part of Table 1 average values are given for the seven analyses. By dividing the molecular ratio of SiO_2 by 32, a number is obtained by which each molecular ratio is divided. The quotients represent the oxide molecules given in column 9 (Table 1). These are multiplied by the molecular weights of the oxides to arrive at the total average molecular weights in column 10. Columns 11 and 12 show the average number of positive ions in a unit volume.

Table 2. Number of Positive Ions in a Unit Volume Containing 32 Si Ions

	1	2	3	4	5	6	7	Avg.	*Actual No. in No. 4
Si	32.0	32.0	32.0	32.0	32.0	32.0	32.0		30.3
Al	3.4	4.4	3.7	5.3	5.6	4.1	5.2	29.2	5.0
Fe'''	7.3	8.8	6.0	11.2	12.3	2.9	12.6		10.6
Fe''	15.2	9.0	11.4	7.7	9.6	14.2	3.5		7.3
Mg	2.2	6.3	5.8	4.3	1.5	9.0	9.9		4.0
Mn	0.0	0.7	0.2	0.1	0.3	0.5	0.0		0.1
Ca	0.3	0.0	0.7	0.1	0.4	0.0	0.0	1.9	0.1
Na	1.0	1.2	0.4	0.1	0.0	0.0	0.0		0.1
K	2.0	1.6	1.8	3.0	0.4	0.0	0.0		2.9
H+	32.0	34.0	26.2	26.9	31.0	53.1	43.0		25.4
H−	9.5	8.7	8.2	9.3	12.6	10.7			8.8

* Actual number of ions in four unit cells of specimen No. 4 based on a theoretical density of 2.90.

On account of the great differences in the oxidation of the iron no significant formula is obtained unless the di- and trivalent ions are added. Then it is discovered that this number is close to 29 in each stilpnomelane.

The average comparative formula may then be written:

$$(K_2, Na_2, Ca)O \cdot 16(Fe, Mg)O \cdot 6\text{–}7(Al, Fe)_2O_3 \cdot 32\ SiO_2 \cdot 21\ H_2O$$

or

$$(OH)_{16}(K, Na, Ca)_2\ (Fe, Mg, Al)_{29}Si_{32}O_{93} \cdot 13\ H_2O$$

The total H_2O was reduced by $\frac{1}{2}$ H_2O on account of the unusually high H_2O in analysis No. 6.

Dehydration of Stilpnomelane

The formula just given does not indicate the distribution of H_2O in the structure. Jakob (7, p. 312), for example, thought that the 20 per cent of total H_2O which he obtained below 105°C in analysis No. 2

should be separated structurally. That he was mistaken is evident from the inspection of the two dehydration curves in Fig. 1. Mr. L. C. Armstrong, at the suggestion of the writer, dehydrated samples No. 3 and No. 4 in vacuo with a tensi-eudiometer as described by Hüttig (16). The two curves are quite similar and show a gradual rise to 500°C. No. 4 from Baern reaches this point, however, after a somewhat greater loss of water than No. 3. The difference may be due to the fact that sample No. 4 was much more finely divided than No. 3. Several investigators including L. C. Armstrong[4] have noticed that the physical nature, especially grain size (in other words exposed surface), influences the results somewhat as indicated. The water given off above 500°C most likely is (OH) in the structure and comprises from $\frac{2}{5}$ to $\frac{1}{3}$ of the total. It is for this and structural reasons that $(OH)_{16}$ appears in the last formula above. This also explains why stilpnomelane is stable to a temperature of 560°C, but starts to collapse in every case above this temperature. The residues taken from the tensi-eudiometer after complete dehydration were magnetic in spots, but there had been no oxidation of FeO at the expense of H_2O as was ascertained by two analyses on sample No. 3.

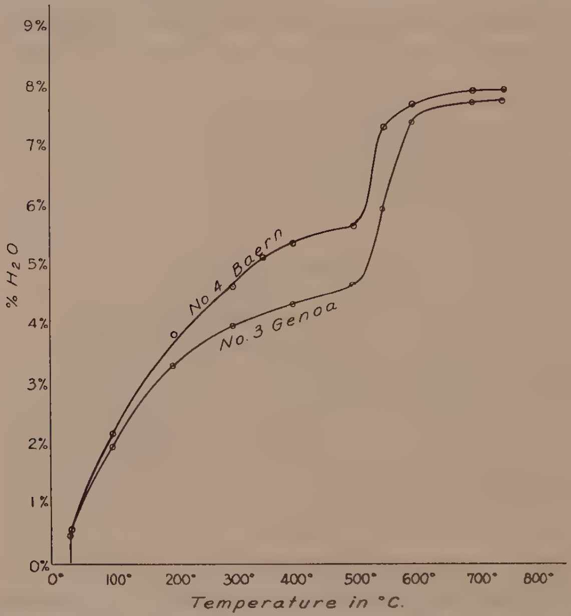

FIG. 1. Dehydration of stilpnomelane carried out in vacuo with a tensi-eudiometer.

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[4] Unpublished data.

DENSITY DETERMINATIONS

Unless the density of a mineral is known it is, of course, impossible to assign the proper number of "molecules" to the unit cell. Accurate density determinations encounter unusual obstacles in stilpnomelane. The mineral is extremely porous between layers so that it is almost impossible to remove all gases. Also it is probable that physical reactions produce colloidal solutions on boiling in distilled water. It was noticed for example that such solutions became opalescent and remained in that state indefinitely. Filtering through dense papers had no effect on them.

Three different methods of density determination were tried, but no two of them produced concordant results. Centrifuging in heavy liquids produced worthless results. Bromoform diluted with alcohol was used. In several trials with apparently homogeneous material from Baern the first fraction to come down had a gravity of 2.67 while the last one settled after dilution to 2.58. The samples of No. 3 and No. 7 behaved in a similar manner but showed still lower values. The reasons for such low results can only be guessed at present. Apparently the gases were not replaced by the liquids. Determinations with the Jolly balance or chemical balance, without any attempts to remove air bubbles, gave higher values than these by one in the first decimal place. The highest values were obtained with the pycnometer and water. A silica glass pycnometer was used. The water was boiled under reduced pressure intermittently for 15 minutes to remove any air from the samples. In this way No. 4 gave 2.87 and 2.89[5] in two determinations. No. 3 has a density close to 2.81.[5] The sample No. 7 has such a peculiar texture that the writer agrees with Shannon (4) that its density cannot be determined by present methods.

One pycnometer weighing was made on a 2.4 gram sample of No. 4 with tetrahydronaphthalene (Spec. Grav. 0.967 at 25°C.). This liquid is especially reliable with clay minerals according to Nutting (18). The sample covered with the liquid was subjected to a partial vacuum for over an hour to extract the air. The specific gravity corrected to 4°C was 2.842. It is believed that the true density of No. 4 is probably close to 2.89, the highest value obtained by any of the methods. Holzner's determination of 2.823 on No. 1 seems to the writer somewhat too low for a stilpnomelane with the highest total iron content of the seven. This may also be the case to a lesser extent with No. 5 which Hallimond determined as 2.85.

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[5] Both corrected to 4°C.

X-Ray Data

It is evident that no idea of the structure of such a complicated mineral as stilpnomelane can be obtained without *x*-ray data. Holzner (2), however, attempted it and thought that it probably was an interstratification of mica and chlorite units. Very recently he (10, p. 448) discarded this idea and mentioned units of kaolinite and mica instead. Such combinations had been investigated two years ago by the writer when he began this *x*-ray study and had been found impossible.

The following materials were investigated by the powder method: Nos. 3, 4, 6, 7, and 8, an unanalyzed stilpnomelane. No suitable specimens for any other method of *x*-ray analysis were discovered. Unfiltered iron radiation was used. Very good diagrams were obtained with the type of camera described by Buerger.[6] The general scattering and darkening near the zero beam was reduced to such an extent that a faint line No. 3 at 6 Å was found which with older equipment had escaped detection. Table 3 contains the interplanar distances and intensities of a number of air dried and specially treated specimens. Other samples give practically identical patterns.

The conspicuous features in the films are always the lines Nos. 1, 2, 3, 5, 7, 9, and 10 which are very sharp and definite. They are undoubtedly reflections from the basal plane with the indices as recorded. It is possible that they need to be doubled as the unit cell may be twice as high as assumed. The reflection No. 2 at 12.1 Å[7] is several to many times as intense as any other reflection. This, coupled with the fact that no other reflections occur between No. 3 and No. 9 (except those indicated), especially no medium to strong ones at about 4.8 Å and 3.45 Å, is of greatest significance. Calculations of theoretical basal reflections show that certain layer structure combinations which are possibilities on the basis of the chemical formula are out of the question structurally. For example, the following are impossible:

1. Interstratification of mica and chlorite units with $d_{001}=24.2$ Å. (For the structure of chlorite see reference 15.)
2. Interstratification of mica and kaolinite layers with a spacing of $d_{001}=24.2$ Å. The kaolinite layers could be all pointing in one direction or could be facing each other as shown in (11, Figs. 2 and 3).
3. Interstratification of mica and vermiculite units (13) with a spacing of 24.2 Å. This combination is also impossible for other reasons, because on heating to 600°C, and even at much lower temperatures, a collapse to 19.5 Å would occur.

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[6] *Am. Mineral.*, vol. **21**, p. 11, 1936.

[7] This spacing is calculated on the basis of the average of the other basal reflections which are much more reliable, being farther away from the zero beam.

Table 3. Powder Photographs of Stilpnomelane

Unfiltered Fe radiation. Camera Radius—57.3 mm.

No.	4.		3.		4.+Tl		4.+$MgCl_2$		Indices
	*d*Å	*I*	*d*Å	*I*	*d*Å	*I*	*d*Å	*I*	
1	12.9	7	13.0	6	13.1	5	13.1	6	β001
2	11.9	10	11.9	10	12.0	10	11.8	10	001
3	6.03	0.5	6.06	0.5	6.06	1			
4	4.74	0.5	4.74	0.5			4.704	0.5	
5	4.476	1	4.446	1			4.440	0.5	β003
6	4.138	0.5					4.138	0.5	
7	4.045	5	4.035	5	4.059	3	4.016	3	003
8	3.566	1b	3.555	1b	3.570	1b	3.522	1b	
9	3.349	1	3.339	1			3.332	0.5	β004
10	3.036	4	3.026	4	3.044	3	3.013	3	004
11	2.831	1	2.818	1	2.815	1	2.831	0.5	β
12	2.693	2	2.702	2	2.689	2	2.708	1	
13	2.549	4	2.560	4	2.557	4	2.562	3	
14	2.481	i	2.508	i			2.513	0.5	
15	2.418	0.5	2.421	0.5			2.426	0.5	
16	2.341	3	2.341	3	2.343	3	2.347	2	
17	2.188	0.5	2.187	0.5			2.191	0.5	
18	2.109	2	2.105	2	2.112	2	2.110	1	
19	1.964	0.5	1.955	0.5			1.955	0.5	
20	1.888	2	1.886	1	1.888	1	1.886	1	
21	1.739	0.5	1.732	0.5			1.729	0.5	β
22	1.686	2	1.686	1	1.692	1	1.686	2	
23	1.576	3	1.577	3	1.575	3	1.586	2	
24	1.561	3	1.563	3	1.560	2	1.570	2	
24a							1.535	0.5	
25	1.519	2	1.517	2	1.522	2	1.513	2	060
25a							1.454	i	
26	1.416	1	1.416	1	1.421	0.5	1.415	1	
27	1.397	0.5	1.399	0.5	1.398	0.5	1.405	0.5	
28	1.359	0.5	1.351	0.5	1.357	0.5	1.368	0.5	
29	1.339	1	1.341	0.5	1.339	0.5	1.346	0.5	
30	1.322	0.5	1.323	0.5			1.327	0.5	
31	1.305	0.5	1.309	0.5			1.310	0.5	
32	1.287	0.5			1.290	0.5	1.282	1	
33			1.229	0.5					
34	1.151	0.5	1.150	0.5			1.153	0.5	
35			1.093	0.5					
Averaged $d_{(001)}$	=12.13		=12.11		=12.18		=12.07		

i = indistinct.
b = broad.

4. Interstratification of mica and nontronite layers (14) with a spacing of 24.2 Å. The collapse mentioned under 3 would also occur.

A number of other combinations of spacings of 12.1 Å and multiples of them were tried but always with results disagreeing entirely with observed intensity measurements. In this way it was finally discovered that the structure could possess an x-ray period of only 12.1 Å, and not a multiple of it. Also almost all the ions would need to be concentrated in three-fourths of the space of the unit cell, leaving an almost vacant layer—as far as ions or atoms with reflecting power are concerned—between densely populated layers. Such a condition would exist if the pyrophyllite or talc units were spaced properly. Unit layers of these have a thickness of about 9.2 Å (12, p. 416). Since stilpnomelane is 12.1 Å thick a vacancy of 2.9 Å is left which could contain some ions or atoms not adaptable to the pyrophyllite layers proper.

The other dimensions of the unit cell are given by line No. 25 which is the reflection of (060). A corresponding line occurs in a very similar position in measured biotites. One other possibility for (060) might have been No. 24 but this would have made the b axis somewhat longer than found in any other similar structure. Besides in the structure treated with $MgCl_2$ this line No. 24 has shifted to a position which would make the b axis entirely too long. With $b_0 = 9.10$ Å on the assumption that the structure is pseudohexagonal, $a_0 = 5.25$ Å. A monoclinic structure with these dimensions and $d_{001} = 12.12$ Å has a unit cell volume of 578 Å^3. If we place in this volume the molecular weight of No. 4 we have the theoretical density:

$$d = \frac{4294 \times 1.65}{4 \times 578} = 3.064$$

This is evidently too high a value. Taking 2.90 as the correct one, the number of all ions in the unit cell is reduced in the ratio of 3.06:2.90. The actual numbers become those recorded in the last column of Table 2.

1.7 ions of Al will be needed to completely fill the 32 available Si positions in four pyrophyllite layers. The actual formula divided by 2 for convenience becomes then:

$$(OH)_8(K, Na, Ca)_{1.5}(Fe, Mg, Al)_{12.6}(Si, Al)_{16}O_{44.5} \cdot 4.5\ H_2O.$$

That of stilpnomelane No. 3 adjusted on the basis of density = 2.81 is:

$$(OH)_8(K, Na, Ca)_{1.5}(Fe, Mg, Al)_{12.3}(Si, Al)_{16}O_{43} \cdot 4.25\ H_2O.$$

Stilpnomelane No. 5 has the adjusted formula:

$$(OH)_8(K, Na, Ca)_{.5}(Fe, Mg, Al)_{11.8}(Si, Al)_{16}O_{42.5} \cdot 5.75\ H_2O.$$

One half of this must be accommodated in the unit cell described. How this may be done is shown diagrammatically in Fig. 2. There is nothing new as far as the pyrophyllite layers are concerned. It is probable that as the ratio of Fe″:Fe‴ increases, some of the (OH) positions become occupied by O, while the hydroxyls may move between the layers to dotted positions to satisfy the Fe ions there (Fig. 2). How far this process can be carried out is a matter of conjecture at present.

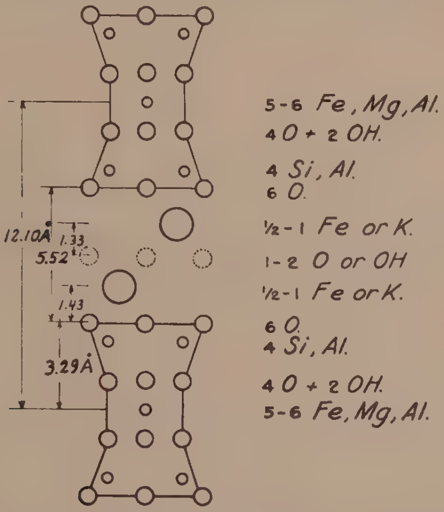

Fig. 2. Proposed structure of the stilpnomelane. Part of the (OH) in the pyrophyllite probably may be replaced by O as Fe″:Fe‴ increases.

The difficulty which confronts one is the location of the (Fe, Mg) and K ions between the layers. It seems reasonable that they occupy the positions held by K in mica, or Ca in brittle micas, only not centered between the layers (Fig. 2). There is room for four such ions in the cell, but only 2 will be needed at the most. The other two may be partially filled by H_2O. The following possibilities are considered for these ions:

1) They are all in random positions. The structure becomes a defect structure (17). Intensities of theoretical basal reflections are recorded under 1, Table 4.
2) The Fe ions are in positions 0.6 Å distant from the oxygen layers of the SiO_4 sheets. A corresponding number of O or (OH) ions are half way between sheets. Case 2, Table 4. The somewhat different position of K is not considered separately in this case.
3) The Fe and K ions are 1.43 Å distant from the oxygen layers of the SiO_4 sheets (Fig. 2). This is about the distance of Ca ions in brittle micas. A corresponding number of O or (OH) ions are distributed at random in this instance. Case 3, Table 4.
4) The positive ions are distributed as in 3 but the O or (OH) ions are half way between sheets. Dotted circles in Fig. 2.

Table 4. Theoretical and Observed Intensities of Basal Reflections of Stilpnomelane

Indices	001	002	003	004	005	006	007	008	009	0010
1	116	½	3	5	0	0	0	0	0	0
2	104	½	6	6	0	0	0	0	0	0
3	83	½	4	3	0	½	0	½	0	0
4	64	0	3	4	0	0	0	½	0	½
Observed Intensities	>10	0–½	4	3	0	0	0	?	0	0

Case 1 does not fit the observed intensities. It is, however, difficult to choose between the other three. In either of the three possibilities there would be just enough room left between the layers to take care of the water molecules. This might be an explanation for the relative constancy of H_2O. In any case the structure may be considered a new type.

Experiments on Base Exchange and Stability

Holzner[8] was the first to point out the fact that thallium easily replaces potassium in stilpnomelane. The writer boiled sample No. 4 four hours in a solution of $TlNO_3$. The analyses of the alkalies afterwards were $Tl_2O = 6.25$, $K_2O = 0.29$, $Na_2O = 0.15$. The specific gravity had increased to 3.00. Theoretically it should have been 3.014. The *x*-ray data for this treated material are recorded in Table 3. There are no appreciable changes in the positions and intensities of the lines, indicating, therefore, possibly random positions for the heavy Tl ions.

Other experiments dealt with the replacement of Fe by Mg for a possible clue to the structure of stilpnomelane. The mineral No. 4 was heated in gold-lined bombs in strong solutions of $MgCl_2$ for 4 days at 300°C. The atmosphere in the bomb was CO_2. There was found considerable Fe in solution. Also the mineral had become reddish brown in color. The *x*-ray results are listed in Table 3, 4th column. While there is some evidence of slight shrinkage in the direction normal to the layers and of some slight changes in intensities, the writer hesitates to interpret these results.

Bomb experiments were also made with weak hydrochloric acid to see whether possible amorphous portions between layers could be removed due to their lesser stability. A 0.03 *N* HCl solution at 300°C did not harm the structure in seven days, except that it dissolved ferrous iron and caused a shrinkage from 12.13 Å to 11.91 Å.

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[8] It may be pointed out that Holzner's specific gravity of 3.068 for the thallium-treated sample is higher than it should be when compared with 2.823 of the natural material. Probably the figure for the latter is too low.

Surprising results were obtained in two experiments in which the concentration of HCl had been increased to 0.1 normal. With No. 4 and No. 7 stilpnomelane a pyrophyllite structure resulted. All the lines in the films agree with those of pyrophyllite. There are considerable differences in sharpness and intensities of the lines but they do not detract from the reality of the structures. It is of interest to note that the same pyrophyllite structure resulted when the writer heated nontronites to a temperature of 575°C (14, p. 476). As a matter of fact these films cannot be differentiated from those obtained in the present experiments, so great is their similarity.

The important question about these experiments is whether the pyrophyllite structure is the original structure of stilpnomelane as assumed above, or whether it is an entirely new development. In the first case, the material between the pyrophyllite layers would have been actually dissolved by the acid causing a collapse to 9.5 ± Å. In the second one the ions liberated by the breaking up of stilpnomelane would have combined to form a new structure. The material is white in color and under the microscope shows fibrous and platy aggregates which, however, are not uniform in behavior. The indices are much lower than would be expected, reaching below 1.48 for α. The birefringence is considerable. Interference figures on large enough plates are almost uniaxial. This phase of experimental work is being continued.

The stability of all the stilpnomelane samples was investigated. It was surprisingly great. In an atmosphere of CO_2 no break-down was noticeable in the structures at 550°C after 24 hours heating. At 600°C the collapse was well underway, and after heating at 640°C new but very poor x-ray patterns were obtained. Apparently the structures shrink in the direction normal to the layers from 12.1 Å to about 11 Å, for the most prominent and strongest line in the new pattern occurs at this spacing.

CONCLUSIONS

A number of stilpnomelanes were investigated. A comparison of the best available analyses gives a formula: $(OH)_{16}(K,Na,Ca)_{0-2}(Fe,Mg,Al)_{29}Si_{32}O_{93}\cdot 13\ H_2O$. It is not feasible to separate the trivalent from the bivalent elements in this mineral on account of the great fluctuations in the state of oxidation of the iron. If all the oxides of Fe, Mg and Al are added it is found, however, that the formula of each stilpnomelane approaches closely the one above. Alkalies are not necessary for the structure of the mineral. Chalcodite is not different from stilpnomelane structurally or chemically, except for the state of oxidation of the iron. Dehydration in vacuo shows that from $\frac{1}{3}$ to $\frac{2}{5}$ of the total H_2O is present in the mineral as (OH). This is not given off until a temperature of 500°C is reached. Dehydration becomes complete at 750°C. Iron is not oxidized in the process of dehydration at high temperature. After about half of the hydroxyl has been lost the structure begins to collapse. This collapse is complete between 600° and 650°C.

X-ray powder photographs of five stilpnomelanes give the following unit cell dimensions based on the assumption that the mineral is pseudohexagonal like other layer structures: $d_{(001)} = 12.07$–12.18 Å, $b_0 = 9.08$–9.12 Å, $a_0 = 5.23$–5.27 Å.

Density determinations of stilpnomelane were carried out only with a great deal of difficulty due to the peculiar physical nature of the mineral. Older values seem to be lower than justified. Pycnometer determinations with water gave the highest values. These were used in determining the number of ions contained in the unit cell of the dimensions given above. By this procedure we obtain the actual formula for an analyzed specimen whose unit cell is known, which is for stilpnomelane from the Genoa Mine of the Mesabi range, namely: $(OH)_8(K,Na,Ca)_{1.5}(Fe,Mg,Al)_{12.3}(Si,Al)_{16}O_{43}\cdot 4.25\ H_2O$.

There exist very good reasons to believe that the structure consists of pyrophyllite-talc layers which are spaced 12.1 Å apart. The space between them contains the ions of Fe, Mg and K which cannot be accommodated in these layers. Also a corresponding number of O or (OH) ions must be present between the layers. The result is a defect structure in which ions may even be in random positions. This is therefore a new type of structure.

The partial replacement of potassium by thallium is described which is indirect confirmation of the proposed structure since it could not take place if the K ions were as closely confined and held as in mica. Experiments in gold-lined bombs at 300°C show that stilpnomelane goes to a true pyrophyllite structure in 0.1 *N* HCl solutions. This phase of the work is being investigated further.

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A METHOD FOR ESTIMATING THE FINISHING BIREFRINGENCE COLOR OF A CRYSTAL OF RANDOM ORIENTATION IN A THIN SECTION

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Due to the variability in thickness of the balsam layer, direct measurements of the thickness of a thin section with micrometers are unreliable. The interference figure does not give a sufficiently accurate indication of the orientation to enable one to estimate what the interference color of the finished thin section, consisting of a single crystal or of extremely coarse rock, should be. Therefore, the following method for estimating the birefringence color for standard thickness has been used.

Designating by t the thickness of the mineral in mm., by n_2 the index of refraction of the slow ray and by n_1 the index of refraction of the fast ray for a particular orientation, the retardation Δ is expressed by the equation

$$\Delta = t\ (n_2 - n_1).$$

This straight line relation can be expressed graphically by plotting the birefringence $(n_2 - n_1)$ for the given orientation with t as abscissa and Δ as ordinate. The slope of the straight line is $\operatorname{ctg} \alpha = \frac{\Delta_1 - \Delta_2}{t_1 - t_2} = \frac{\Delta}{t} = (n_2 - n_1)$.

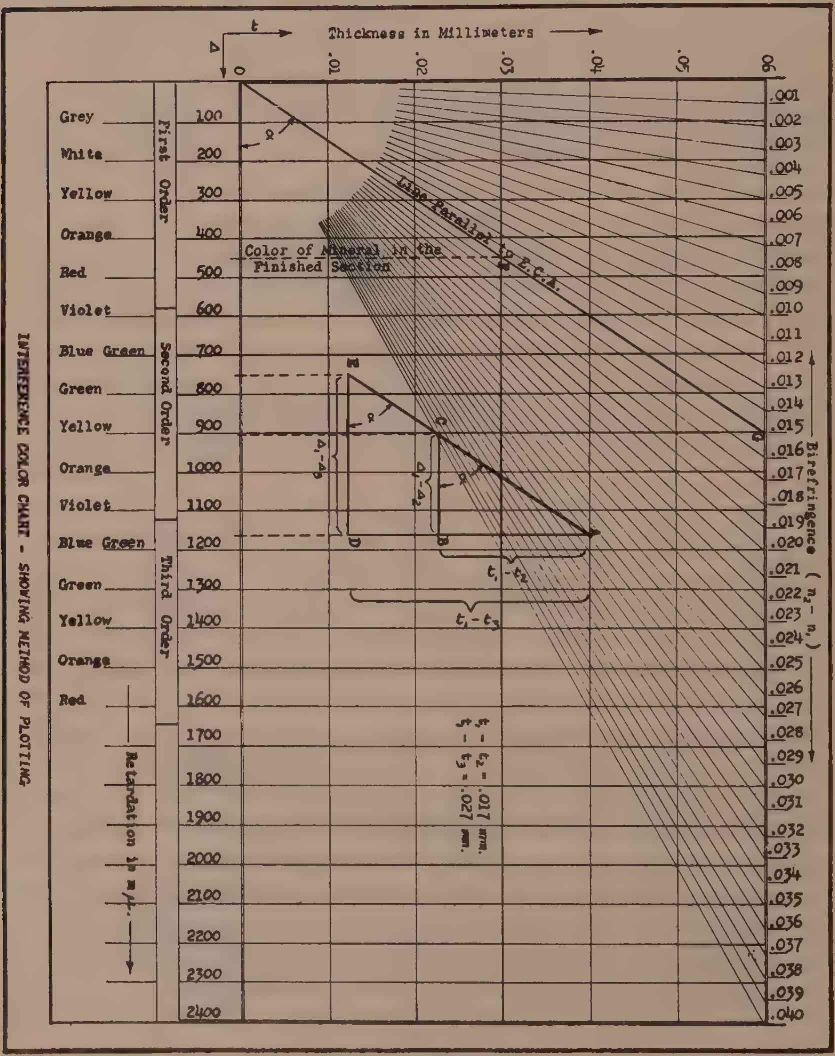
Graphs of this kind are known as interference color charts, since the retardation is either given in the actual interference colors, or is indicated in writing.

The method described here makes use of the fact that the value of ctg α is independent of the actual thickness of the mineral and depends only upon the difference $(t_1 - t_2)$ and the corresponding $(\Delta_1 - \Delta_2)$. For the determination of ctg α, one finds, therefore, t_1 and the corresponding Δ_1 for any thickness. Then one grinds the mineral a little thinner and finds the values of t_2 and Δ_2. It is now easy to plot or calculate $(n_2 - n_1)$ $= \frac{\Delta_1 - \Delta_2}{t_1 - t_2} = \operatorname{ctg} \alpha$ and to find the birefringence line corresponding to this value $(n_2 - n_1)$ on the interference color chart. The point of intersection of this line with the horizontal line for the thickness 0.03 mm. shows the retardation or birefringence color that this particular crystal should have in the finished section.

The thicknesses t_1 and t_2 can either be determined by micrometer measurements to .003 mm., or with the microscope by focusing the high power objective and reading on the fine adjustment screw the difference in heights. The retardation is determined by compensation with the quartz wedge and comparison of the colors on the chart. Care should be taken to have the slide clean and to take the measurements as nearly as possible at the same point. The errors introduced in t_1-t_2 by the micrometer measurements are due to the unequal pressure on the micrometer screw in the two individual measurements, and uncleanliness of the slide; the first of these can be eliminated by the use of a dial gauge. The factors which influence the microscope measurements are: first, the area of the slide in contact with the stage is comparatively large, and errors due to uncleanliness are more difficult to avoid; second, the high power objective must be focused upon a comparatively rough surface and the accuracy depends entirely upon the sensitivity of the observer's eye.

In order to illustrate how this method is applied, the following example is given: The section which consists of a single crystal of an unknown mineral, or a mineral at random orientation, is ground until it shows a clean blue interference color. The section is cleaned and at an easily determinable point the micrometer measurement is taken. This measurement reads $t_1=1.597$ mm. The compensation with the quartz wedge shows that the blue is of the third order and corresponds to a Δ_1 of 1150 mμ. Now the section is ground until the blue has changed to a bright yellow and the measurements are repeated, whereby t_2 is determined to be 1.580 mm. and the corresponding Δ_2 is 900 mμ. For the purpose of checking, another measurement is taken for bright green and gives $t_3=1.570$ mm. and $\Delta_3=750$ mμ. From these measurements we find $t_1-t_2=.017$ mm. $=AB$ (see Fig.); $t_1-t_3=.027$ mm. $=AD$; $\Delta_1-\Delta_2=250$ mμ $=CB$, and $\Delta_1-\Delta_3=400$ m$\mu=ED$, from which $\frac{\Delta_1-\Delta_2}{t_1-t_2}=\frac{.00025}{.017}=.00147$. $\frac{\Delta_1-\Delta_3}{t_1-t_3}=\frac{.00040}{.027}=.00149$. According to these determinations the finishing birefringence color should be a deep orange of first order. It is still simpler to put a sheet of tracing paper over the interference color chart and plot the retardation Δ directly according to the colors of the chart—as shown in the illustration—and to use the vertical division of the chart for plotting $(t_1-t_2)=AB$ (see Fig.). After closing the triangle ABC by drawing the line CA we draw a line OG parallel to the long side CA through the origin of coordinates O, the intersection of which with the horizontal line for standard thickness (point F in the Fig.) indicates the finishing color.

Although due to the possible errors, especially in the determination of t_1-t_2, this method can be regarded only as an estimate of the finishing birefringence color, it is a valuable guide when dealing with single crystals at random orientation, or with an extremely coarse rock. In a series of measurements it has been found that the error in the estimated finishing thickness varies at an average within .008 mm., which corresponds in the case of quartz to a finishing color between straw yellow and white. If unfamiliar minerals occur in a fine-grained rock, one can apply this method in a similar manner, using the crystals of highest interference colors. The accuracy of this method decreases with increasing birefringence with respect to the values of Δ for the finishing color; the variation for the determination in thickness remains, however, within the same limits.



NOTES AND NEWS

LOPEZITE, A NEW MINERAL

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In 1935 the writer spent several months in Chile collecting minerals for the United States National Museum and the Mineralogical Museum of Harvard University. Suites of specimens were collected from several nitrate oficinas on both the Tocopilla and Iquique pampas.

Among the specimens from the oficina Maria Elena, near Tocopilla, and from the oficina Rosario on the Iquique pampa, were several that carried an orange red mineral in vugs with all the appearance of potassium dichromate. This mineral, occurring in very small amounts, insufficient for chemical investigation, was examined optically and found to have, indeed, properties identical with artificial potassium dichromate. The optical data on the natural and artificial minerals are given below.

Lopezite	Artificial $K_2Cr_2O_7$[1]
$\alpha=1.714$	1.7202
$\beta=1.732$	1.7380
$\gamma=1.805$	1.8197
X = reddish yellow	red
Y = yellow	
Z = greenish yellow	yellow
2V = 50°	2V = 51°53′
$r>v$, medium	$r>v$
Color = orange red	Aurora red

The mineral is easily soluble in water to an orange solution, which yields characteristic microchemical tests for potassium and dichromate.

Natural potassium chromate, tarapacaite, has long been known from the Iquique pampa and the occurrence of potassium dichromate is entirely expectable.

As stated above the potassium dichromate occurs in vugs in massive caliche, implanted on tarapacaite and dietzeite (Maria Elena). It is found in the form of balls about a millimeter in diameter. Implanted on the potassium dichromate are small, radiating crystals of ulexite. Some areas of niter are faintly colored orange suggesting included dichromate, but the few small crystalline areas are confined to the vugs. Tarapacaite, on the other hand, is plentifully sprinkled through the niter mass.

The sequence relationships are: tarapacaite, potassium dichromate, with ulexite the last mineral to form. From the relationships between early potassium chromate and later potassium dichromate it appears that the solutions depositing the caliche minerals became enriched in chromium oxide during crystallization. Other field relationships amply support this. The sequence relationships of dietzeite are not clear, suffice to say that it is later than the nitrate minerals and earlier than the bulk of the pure chromates.

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[1] Groth, P., *Chemische Krystallographie*, Part II, p. 587.

There was not a sufficient quantity of the mineral to permit an analysis. Due to the intimate association with potassium chromate it would have required careful cleaning of a large quantity of material to obtain a satisfactory sample. Crystals were observed but were not suitable for measurement. A new mineral name is being suggested on the minimum of data, but due to the close parallel of properties with those of a well known artificial compound it is believed that there is little doubt as to its true nature and a species name is justified. It is with pleasure that the writer suggests the name *lopezite* in honor of Dr. Emiliano Lòpez of Iquique, a mineral collector who has been associated with the nitrate industry in Chile for many years.

The writer wishes to thank the United States National Museum and the Mineralogical Museum of Harvard University for permission to publish this data.

AN UNUSUAL OCCURRENCE OF HALITE

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Recently C. J. McKie, Superintendent of the Quincy Mine, and Professor W. A. Seaman of the Michigan College of Mining and Technology found large quantities of halite at the 85th level of the Quincy Mine, Hancock, Michigan. Since the Quincy is a copper mine located in Keweenawan lava flows far removed from sedimentary strata known to contain halite, and especially since many of the crystals show well-developed octahedral faces, it is believed that the occurrence and the mineral are worthy of description.

Sodium and chlorine are commonly found in the deep mine waters[1] of the Michigan Copper Mines. Halite has been mentioned[2] but once and then only as a few crystals found on the 9th level of the Hecla Mine.

The mineral occurs in the form of stalactites, stalagmites and encrustations on the walls as well as on the floor. There are even a few slabs as large as a foot square and two inches thick. The halite varies from coarse crystals of about one inch cubes to very fine thread-like crystals. These fine crystals are so fragile and delicate that even a slight breeze loosens them from the walls and produces what appears to be falling snow. The

[1] Dripping on 55th level north of No. 6 shaft, Quincy Mine

Cl	176.027 gm. per liter
Br	2.200
Ca	86.478
Na	15.188
K	.411
SO_4	.110
SiO_2	.020
Fe_2O_3 & Al_2O_3	.010
Mn	.004
Cu	.016
Mg	.020
Sr & B	trace
Sum	280.489
Difference	.011
Total solids	280.500 determined

This is the most complete analysis made of the deep water and may be taken as the standard. It is worth noting that calcium and sodium chlorides form 99% of the total salts, and calcium and sodium bromide form three-fourths of the remainder.

Lane, A. C. The Keweenaw Series of Michigan: *Mich. Geol. Survey*, Pub. **6** (Geol. ser. 4), p. 794, 1908.

[2] *Idem.*, p. 859.

larger needle-like crystals show square terminations; in other words, they are distorted cubes. Although the large crystals are cubes, many are modified by octahedrons, as shown in Fig. 1. They have a salty taste, perfect cubical cleavage, hardness of 3, and a specific gravity of 2.11. The low gravity is probably due to air bubble inclusions. Most of the material is coated with yellow-reddish mine sludge that washes off very readily, leaving the crystals pure white. There are also other encrustations, some red, others green; but not enough of these have been collected for determinative work.

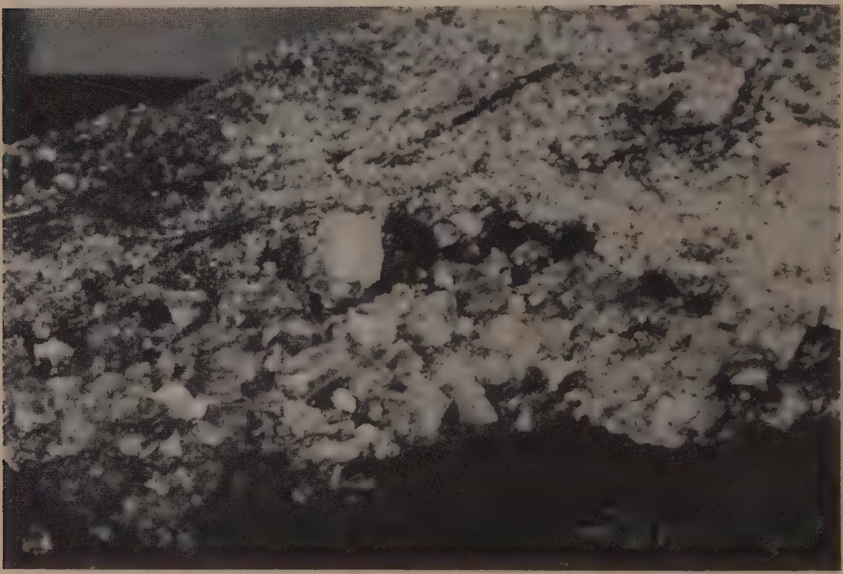

FIG. 1. Halite showing cube in combination with the octahedron.

The brown-colored material was analyzed by R. F. Makens as follows: It was washed and dried to constant weight at 110°C. The resulting material consisted of nearly colorless cubic crystals. A qualitative analysis showed traces of Fe^{+++}, Ca^{++}, and SO_4^{--} associated with relatively large amounts of Na^+ and Cl^-. 0.07% of the original material was found to be insoluble in water.

The Na^+ was determined quantitatively as $NaZn(UO_2)_3(C_2H_3O_2)_9$ $6H_2O$ according to the directions of H. H. Barber and I. M. Kolthoff,[3] and the chloride was determined by precipitating and weighing as silver chloride. The per cent Na^+, found as an average of five determinations, was 39.5%; and the per cent Cl^-, found as an average of two determinations, was 60.76%. The theoretical percentages of Na^+ and Cl^- in pure NaCl are 39.32% and 60.68%, respectively.

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[3] *Jour. Am. Chem. Sec.*, vol. **50**, pp. 1625–31, 1928.

X-ray diffraction patterns[4] of the Quincy halite and known sodium chloride were identical.

The part of the 85th level where the halite was found in such abundance has not been in use for six years, and the drift is subject to a continuous air current. As the walls, floors, and crevices are covered with halite in a manner similar to the occurrences of calcium carbonate in limestone caves, it is believed that the halite was precipitated by evaporation from waters as they oozed from crevices in the rock or concentrated in small pools on the floor.

[4] Fisher, F.

SOME OCCURRENCES OF KAOLINITE DEPOSITED FROM SOLUTION

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During their recent study of dickite in Missouri,[1] the authors found kaolinite in several localities in which its occurrence gave unmistakable evidence that it had been deposited from solution. These localities were Oronogo Circle mine, Oronogo, Missouri; the National Pigment and Reavis barite mines near Henley, Missouri; and Keokuk, Iowa. Oronogo is in southwestern Missouri; the Henley locality is in central Missouri; and Keokuk is just across the Missouri-Iowa line at the northeastern corner of the state of Missouri. The kaolinite in all these localities is pure white, and occurs in very small crystals. Under a lens, the tiny flakes glisten like snow.

In the Oronogo Circle mine, the kaolinite occurs as thin veins in nearly vertical joints of the Pennsylvanian shales, as well as in cavities and as a replacement mineral. The veins in the shales are simple filled fissures, on the walls of which minute quartz crystals have been deposited, followed by the kaolinite. Some ore specimens show the sulfides, sphalerite and galena, deposited on the quartz with the kaolinite following them. At the Circle mine, some kaolinite occurs in cavities in the rocks, and also replacing coarsely crystalline calcite in cavities or even calcite deposited as veins. The evidence that the kaolinite at the Oronogo Circle mine was deposited from solutions is beyond doubt.

The kaolinite at the National Pigment barite mine was deposited in joints (in Jefferson City dolomite) that had been enlarged by solution. Minute dolomite crystals and pyrite (now limonite) were deposited before the kaolinite. The veinlets of kaolinite rarely exceed one millimeter in thickness and are not persistent along the joints.

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[1] Tarr, W. A., and Keller, W. D., Dickite in Missouri: *Am. Mineral.*, vol. **21**, pp. 109–114, 1936.

At the Reavis mine, the kaolinite occurs dominantly in solution cavities and along joints in the Jefferson City dolomite. It is patchy in the joints, as well as in the solution cavities, none of which exceed one inch in diameter. Barite, galena, chalcopyrite, pyrite, and marcasite, all occur with the kaolinite, but in small quantities, save the barite. Both this mine and the National Pigment mine are in sink holes.

The kaolinite in the Keokuk, Iowa, area occurs in quartz geodes and small solution cavities in siltstone. The material is most abundant in a prominent siltstone member of the shale series exposed at the north end of the bridge over the Des Moines River, and in quartz geodes in a siltstone exposed near the top of the large quarry at the east end of the Keokuk dam. A few other minor occurrences were noted in Keokuk and to the north of the city. In the siltstone at the bridge, the kaolinite occurs in quartz-lined geodes that are distributed along a well defined zone. A row of smaller cavities occurs near the bottom of the siltstone. Few of the geodes exceed three inches in length. The kaolinite occurs in the lower part of the cavities, showing that after crystallizing it settled downward in a solution. All but a few of these geodial and solution cavities contain pure white, crystalline kaolinite, some being completely filled with it. At the east end of the Keokuk dam, all the kaolinite occurs in quartz (or chalcedony) geodes, some of which are 8–12 inches in diameter. The quartz crystals in the geodes have a radial arrangement. Only traces of sulfides were found. As the outer shell of the geodes is thin, most of the large ones have been crushed. Some geodes occur in the limestone below, but these do not contain kaolinite. It should be noted that dickite has been reported[2] from a geode in this vicinity, but the writers found none in the material they collected. The occurrence of the kaolinite in this area, as in all the others described, points absolutely to deposition by solutions.

The determination of the kaolinite was made by optical methods as far as particle size permitted, and was confirmed by x-ray tests.

The kaolinite from the Oronogo Circle mine averaged about .016 mm. in diameter, and lay in a tightly packed condition in the veins. Consequently, triangular warped books (or sheaves) made of flakes were preserved in the immersion oil suspension. A few crystals showing part of a hexagon were preserved but, in general, anhedral flakes prevailed. Indices on the clay were: $\gamma = 1.566$, $\alpha = 1.561$, $\pm .002$. X-ray patterns made of this material by Professor Paul F. Kerr showed it to be kaolinite.

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[2] Ross, C. S., and Kerr, Paul F., The Kaolin Minerals, *U. S. Geol. Surv., Prof. Paper*, **165 E,** p. 158.

The clay from the National Pigment mine was similar to that from Oronogo in size of flake and tightness of packing. Perhaps a few crystals remained less torn when mounted in oil, but the general appearance of the material was practically the same as that from Oronogo. Indices were: $\alpha=1.561$ or 1.562, and $\gamma=1.566$. *X*-ray confirmation of kaolinite was not made because comparison of this sample with known kaolinite and dickite left little doubt in the writers' minds that it was kaolinite.

The Keokuk kaolinite lay rather loose (unpacked) in the protecting geodes and, therefore, could be transferred to a microscope slide with a minimum of crystal breakage. Separation into a suspension in the immersion oil took place readily with the result that the minute kaolinite flakes were fairly well outlined as individuals. Six-sided crystal flakes were uncommonly well developed for kaolinite, but less regularly than is usual with dickite. No doubt, the excellent preservation of the crystals was possible only because of the lack of packing within the geode.

Crystal flakes averaged about .006 mm. in diameter with but little deviation, and this small size made precise index of refraction determination impossible. In oil of 1.566 index the flakes disappeared, but they were visible in oils whose indices were .005 above and below. Gamma is probably close to 1.565. Alpha, and the other optical constants, could not be determined. *X*-ray patterns were run on two samples submitted to Professor Paul F. Kerr, and both specimens were reported by him[3] to be kaolinite.

In summary, we may say that the white powdery material (which has been shown by optical studies and *x*-ray analyses to be kaolinite) found in these three areas is proved by its mode of occurrence and crystalline character to have been deposited by solutions capable of its transportation.

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[3] Personal communication.

Dr. Norman L. Bowen, petrologist at the Geophysical Laboratory of the Carnegie Institution of Washington, D.C., has been appointed first Charles L. Hutchinson distinguished service professor in the department of geology of the University of Chicago. Professor Bowen will succeed Dr. Albert Johannsen who has retired after having served twenty-eight years as professor of petrology. The Charles L. Hutchinson professorship has been established by the Board of Trustees in recognition of the interest taken by the late Mr. Hutchinson in the University, of which he was for many years a trustee and treasurer, and of Mrs. Frances K. Hutchinson.

The Mineralogical Society of America was incorporated under the laws of the District of Columbia on June 17, 1937, by Norman L. Bowen, John Frank Schairer and Waldemar T. Schaller.

BOOK REVIEW

INTRODUCTION TO THE STUDY OF MINERALS, by AUSTIN FLINT ROGERS. Third edition, xviii+626 pages, 6 by 9 inches, 729 figures, 1 plate. Price $5.00. McGraw-Hill Book Co., **1937**.

This new edition of the well known Stanford text appears in an enlarged, modernized format, almost disguising the familiar "pocket manual" of 1912 and 1921. The substance has been improved no less than the outward appearance.

About equal importance is given to morphological, physical and chemical properties, which are taken up in that order. The crystallography is exceptionally good in view of the limited space available and despite the fact that few proofs can be given in an introductory book of this sort. The treatment is based on one-circle goniometry. All 32 crystal classes are discussed, with special stress on the 11 mineralogically important ones. The difficult alternating symmetry is not skipped, but explained; the axes of composite symmetry of even period are preferred (AP_4, AP_6, CA_6). The author points out the advantage of the center of symmetry over a 2-fold rotoflection axis undefined in direction. The plane of symmetry is, of course, preferred to the 2-fold rotoversion axis. The baffling relation between crystal symmetry and crystal malformation is clearly shown. The linear projection is revived to bring out zonal relations, a problem for which it is particularly adequate. Professor Rogers' recognition of 4 types of zones and integrity of zone character (independent of temperature) leads to a re-definition of the 6 crystal systems that leaves nothing to be desired.

The stereographic projection is introduced. For illustration purposes the stereographic pole is replaced by a small geometric figure (triangle, rectangle, etc.) aiming at picturing the projected face. This novelty is likely to be found of value in elementary teaching. Some purist might resent the liberty taken with the principle of the projection; his objection would be easily met if the actual pole were retained as a point inside the "face figure." The determination of axial elements and face symbols is very simply solved by descriptive geometry (plan and elevations), with the *Addition and Subtraction Rule* as a valuable auxiliary. Clinographic drawing is based on the "axial cross" procedure, which is somewhat cumbersome but certainly illuminates the Millerian notation for the bewildered student. Overloading of the nomenclature of merosymmetric forms has been carefully avoided; teachers will appreciate this. In the 5 classes of the rhombohedral subsystem, the 3-index notation is recommended when the space lattice is rhombohedral. The recently discovered systematic "morphological extinctions," due to space group symmetry, make this desiratum less imperative now, since the rhombohedral lattice can be considered a centered mode of the hexagonal, thus fitting perfectly with the division into 6 crystal systems.

The terminology of the crystal classes is that of the general forms (Groth); this is sufficient justification for considering the dome and the sphenoid two distinct forms. Although the definition of the twin axis only mentions the 180°-rotation, and includes the statement that a twin axis is never an even-fold symmetry axis, the possibility of twinning by other than 180° rotations is implied in the "iron cross" law, given as twin axis [001]. This seems worthy of mention because so few authors recognize this important fact about twinning. Stress is laid on the centrosymmetric character of cleavage, discussed in the crystallographic section as indeed it should be, since it is one of the 5 discontinuous vectorial properties typical of crystalline matter. The chapter on crystal structure has been enlarged, but not beyond the bounds imposed by the scope of the book. The author contrasts the 7 primary lattices with the 6 crystal systems. Among points of interest seldom found in text books is Friedel's *Law of rational symmetric intercepts:* a crystal polyhedron may have an irrational 3-fold axis of symmetry and still obey Haüy's Law of rationality of indices (proof given); irrational 3-fold axes, on the other hand, cannot exist in space lattices; Friedel's law of observation (1905) that crystals have no irrational 3-fold axes left only the lattice hypothesis open.

The treatment of crystal optics remains essentially the same, with several additions and with increased emphasis on the index ellipsoid as the only optical surface necessary for pedagogic purposes. In the chemical part, a well illustrated 17-page section on microchemistry (by Lloyd W. Staples) is a good addition. In the descriptive mineralogy the recommendations of the British-American committee on nomenclature are followed. The number of species has been increased by 47, bringing the total to 222 minerals and mineraloids. Of these, about 60 are distinguished by larger type. By indicating the crystal system (or class) and the chemical formula (in bold face), next to the mineral name in the heading, a decided improvement is effected. The alteration of minerals is also given more importance. The German and French synonyms, given for each mineral name, may be found useful, especially the German ones for sulfides and sulfo-salts! As a finishing touch to each mineral description, a short historical sketch is given with the derivation of the name. The species are listed according to the usual chemical classification. The silicates come last, a scheme, long advocated by Professor Rogers, which will be adopted in the 7th edition of Dana's System.

The part dealing with occurrence and genesis is a lucid presentation of the geological rôle of minerals. The last chapter, on mineral identification, includes determinative tables well designed to develop the difficult art of sight recognition. A reference list of minerals and a carefully prepared index and glossary are appended.

Except for a moderate number of misprints, the material presentation of the book measures up to the best standards.

J. D. H. Donnay.

PROCEEDINGS OF SOCIETIES

ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF SOUTHERN CALIFORNIA

Edwin V. Van Amringe, instructor in geology at Pasadena Junior College, was unanimously re-elected president of the Mineralogical Society of Southern California at the annual meeting held on the evening of June 12th. Other officers elected were: Franklin G. McIntosh of Beverly Hills, vice-president; Herman Abraham of Pasadena, secretary; and Kenneth N. Reed of Pasadena, treasurer. The new board of directors will consist of Earl L. Calvert, San Gabriel; Ernest W. Chapman, South Pasadena; Heber H. Clewett, San Dimas; Morris R. Ebersole, Hollywood; John M. Grieger, Pasadena; John A. Renshaw, Arcadia; and David B. Scott, Altadena. The business meeting was preceded by a banquet for 120, and a concert. A large variety of beautiful minerals and gems were exhibited by the members.

Extracts from the Annual Report of the President of the Mineralogical Society of Southern California

On this, the sixth anniversary of our Society, I take pleasure in reviewing a little of the history of its founding and development. It was in the spring of 1931 that John Renshaw sent out about sixty-five announcements of an organization meeting. On the evening of June 23rd, forty people were gathered in the lecture room of the Pasadena Public Library, and I had the pleasure of addressing them on "Mineral Collecting as a Hobby." The first issue of our *Bulletin* appeared in November, 1931, and continued regularly until it was combined with that of the Oregon society just three years later.

The Society progressed steadily in the two-year term of Ernest Chapman, and at the time of my election last June, meetings had totaled fifty-two, with thirty-two field trips. Our president had assisted greatly in the formation of the California Federation of Mineralogical Societies, which had its real beginning on "Mineralogy Day" at the San Diego Exposition, June 16, 1935. The first convention was held at Riverside on January 4th and 5th, 1935, with over five hundred attending. The officers then elected are still holding office. The second annual convention at Bakersfield on January 2nd and 3rd, 1937, was an outstanding success, and plans were laid for the San Francisco event on February 21st and 22nd of next year.

During the current year we have enjoyed the following excellent lectures: In September Harry R. Newitt of Los Angeles spoke on "Mine Salting"; in October, W. L. Cozzens of the Fairchild Aerial Surveys illustrated aerial mapping with relation to geology; in November, Dr. H. J. Fraser of the California Institute of Technology told of his prospecting for gold in the Hudson Bay region; the January meeting featured Wendell Stewart's pictures of his trip to the gem cutters of Idar, Germany; in February Dr. H. L. Hatfield exhibited colored motion pictures of the western National Parks; Dr. Beno Gutenberg of the California Institute of Technology discussed his revolutionary work on structure of the earth's crust in March; Alvin B. Carpenter in April told of his development of old Spanish mines in Mexico; and in May Roy Martindale of Glendale illustrated the determination of minerals by means of the microscope. Our field excursions for the year included a trip to the Stauffer borax mines near Frazier Mountain, an evening trip through the mills of the Columbia Steel Corporation at Torrance, a nine-day trip to the copper districts of southeastern Arizona, a visit to the Joshua National Monument and the Dale district, and a collecting trip to the Juniper Flat pegmatites and Winchester magnesite quarry.

Among other special events of the year I should mention the visit of Fred Young of Oregon in November, and the consequent publication of the special 120-page California number of our journal, "The Mineralogist"; the fine exhibit of minerals now in the Griffith Planitarium arranged by John Akers, Harold Reed, Morris Ebersole and John Grieger: the exhibit belonging to Wendell Stewart now on display in the Pasadena Public Library: and the sad deaths of two of our active members, Harry Hyatt of Corona and Dr. S. E. Sanger of Monrovia.

EDWIN V. VAN AMRINGE, *President*